ASSESSMENT OF ECOLOGICAL STATUS OF Godavari River

FOR CONSERVATION PLANNING

ASSESSMENT OF ECOLOGICAL STATUS OF Godavari River

FOR CONSERVATION PLANNING

This document is an output of the project entitled “Assessment of the ecological status of select Indian rivers for conservation planning” sponsored by the National River Conservation Directorate (NRCD),

Ministry of Jal Shakti, Government of India, New Delhi.

Principal Investigators
Ruchi Badola, Syed Ainul Hussain

Coordinating Lead Authors
Syed Ainul Hussain, Ruchi Badola

Lead Authors
Tanveer Ahmed, Aakash Maurya

Contributing Authors
Narendra Mohan Katara, Ajay Gaikwad, Dinesh V., Suyash Katdare, Renu Kumari, Prabal Kumar, Anisha Ganguly, Anshu Panwar, Kamran Hussain

Maps and Database
Anil Fartiyal, Gajendra Kumar

Additional Inputs
Shivani Barthwal, Surya Prasad Sharma, Ruchika Sah, Sk Zeeshan Ali, Pooja Chaudhary

Copy editing
Ombir Singh
Forest Research Institute (FRI), Dehradun

Reviewer
Justus Joshua
Green Future Foundation

© National Centre for River Research
Wildlife Institute of India, Dehradun

ISBN No. (Print): 978-93-49520-76-9
ISBN No. (Electronic): 978-93-49520-09-7

Citation
Hussain, S.A., Badola, R., Ahmed, T., Maurya, A., Katara, N.M., Gaikwad, A., Dinesh, V., Katdare, A., Kumari, R., Kumar, P., Ganguly, A., Panwar, A., Barthwal, S., Sharma, S.P., Sah, R., Ali, S.Z., Chaudhary, P., Fartiyal, A., Kumar, G. and Hussain, K. (2025). Assessment of ecological status of Godavari River for conservation planning, Wildlife Institute of India, Dehra Dun. Uttarakhand, India. 324 pp.

Ministry of Jal Shakti
Chandrakant Raghunath Patil, Hon'ble Union Minister
Raj Bhushan Choudhary, Hon'ble Union Minister of State
Debashree Mukherjee, Secretary

National River Conservation Directorate (NRCD)
Rajeev Kumar Mital, Director General, NMCG and Project Director, NRCD
Pradeep Kumar Agrawal, Joint Secretary
Sushil Kumar Srivastava, Scientist F
Sabita Madhvi Singh, Scientist E

Ministry of Environment, Forest and Climate Change
Bhupendra Yadav, Hon'ble Union Minister
Tanmay Kumar, Secretary
Sushil Kumar Awasthi, Director General of Forest & Special Secretary
Anjan Kumar Mohanty, Additional Director General of Forest
Ramesh Kumar Pandey, Inspector General of Forest

Special gratitude
Gajendra Singh Shekhawat, Former Union Minister of Jal Shakti, Government of India
Pankaj Kumar, Former Secretary, Ministry of Jal Shakti
Leena Nandan, Former Secretary, Ministry of Environment, Forest and Climate Change
Rajiv Ranjan Mishra, Former Special Secretary and Director General, NMCG and Project Director, NRCD
G. Asok Kumar, Former Special Secretary and Director General, NMCG and Project Director, NRCD

Department of Environment and Forest. Government of Maharashtra, Telangana and Andhra Pradesh

Wildlife Institute of India
Virendra R. Tiwari, Director

WII Faculty and NRCD Team

ACKNOWLEDGMENTS

PREFACE

Freshwater ecosystems are the most bio-diverse ecosystems. These systems harbour 9.5% of all animal species, nearly 6% of all described species, and 1/3 of all vertebrate species. Among the freshwater ecosystems, rivers are more prone to large-scale modification due to land use changes with the rise in human population and the increasing demand for energy, and food, which are manifested in the form of dam construction, water withdrawals, pollution, invasive species, and over-harvesting. Rivers in India are water-stressed due to demand in domestic, industrial, and agricultural sectors. The construction of 5264 large dams has altered the natural flow regime of most of the rivers and subsequently reduced the carrying capacity for pollutants. These large multipurpose dams have altered the morphology of the rivers, fragmented river habitats, and impacted aquatic species' occurrence and distribution. 63% of the 61,948 Million Litre per Day (MLD) sewage generated from Class I and Class II cities in and around these river basins are discharged into the rivers untreated. Increasing river traffic due to 111 national waterways is not only detrimental to aquatic species but also facilitates the proliferation and spread of non-native aquatic species. Owing to these anthropogenic stressors, the resulting habitat degradation, alterations, invasive species spread , and over-exploitation, the aquatic species within these river basins are under stress while some species have become locally extinct. Given this, a consultative meeting was held on 16th December 2019 at the National River Conservation Directorate, Ministry of Jal Shakti to identify the major Indian rivers for conservation prioritization. It was suggested that the Biodiversity Conservation and Ganga Rejuvenation model implemented by the Wildlife Institute of India (WII) under the National Mission for Clean Ganga project should be replicated to start the nationwide river conservation project, and WII can be the nodal agency. It was proposed that the rivers Barak, Cauvery, Godavari, Periyar, Mahanadi, and Narmada shall be taken as priority rivers as suggested by His Excellency Ram Nath

Kovind, President of India, in the Parliament. Subsequently, a video conference meeting was chaired by the Hon'ble Minister for Jal Shakti, Shri. Gajendra Singh Shekhawat, on 11th April 2020 on Biodiversity Conservation projects implemented through WII. The Hon'ble Minister directed WII to replicate the river conservation model to other Indian rivers and priority shall be given to the rivers mentioned by the Hon'ble President of India. In the follow-up meeting on 23rd April 2020, under the chairmanship of the Director General (DG), NMCG, DG recognized WII as an umbrella agency to spearhead biodiversity conservation in six Indian rivers viz., Barak, Narmada, Mahanadi, Godavari, Cauvery, and Periyar under the aegis of the National River Conservation Directorate (NRCD). Present report is an outcome of the extensive surveys carried out in Godavari River basin under the project “Assessment of the ecological status of the select Indian rivers for conservation planning”. This report, titled " Assessment of the ecological status of the Godavari River for conservation planing, provides an in-depth exploration of the diverse ecological aspects of the Godavari River. It encompasses a comprehensive analysis of the riverbank vegetation, fish, reptiles, birds, and mammals, including a focus on the conservation status of threatened flora and fauna. The report concludes by emphasizing the critical conservation challenges and offering management recommendations for the sustainable preservation of the Godavari River and associated freshwater ecosystems.

Ruchi Badola

Syed Ainul Hussain

सी आर पाटील
C R Paatil

सत्यमेव जयते

जल शक्ति मंत्री
भारत सरकार

Minister of Jal Shakti
Government of India

Message

Indian rivers are the lifeline of our nation, sustaining millions of people, diverse ecosystems, and countless species of flora and fauna. However, these vital water bodies are facing many challenges due to various anthropogenic pressures, requiring an urgent need for effective conservation. I commend the efforts of National River Conservation Directorate (NRCD) for their initiative towards river conservation planning from biodiversity angle with the help of Wildlife Institute of India, Dehradun.

Wildlife Institute of India has used its expertise in vogue for assessing ecological status of select Indian rivers and have identified priority areas that need protection. I am highly impressed with the dedication and work demonstrated by Wildlife Institute of India in this endeavour. Furthermore, I strongly advocate for replication of such studies in other rivers in India, so that a comprehensive ecological status of Indian rivers could be developed. Such initiatives are vital for restoring and maintaining ecological balance of our river systems. The combined efforts of NRCD and WII would pave the way towards a healthier and more sustainable environment.

I strongly recommend that NRCD, should continue to make significant strides in conservation of our invaluable rivers and their biodiversity. I am confident that the respective State Governments will strive to implement the recommendations given in this report for maintaining the Vibrant, Aviral and Nirmal Dhara of the Indian rivers. I wish WII in their future endeavours.

(C R Paatil)

डॉ. राज भूषण चौधरी
Dr. Raj Bhushan Choudhary

सत्यमेव जयते

जल शक्ति मंत्री
भारत सरकार
नई दिल्ली–110001
Minister of Jal Shakti
Government of India
New Delhi-110001

Message

River, with its rich biodiversity and ecological significance, is a vital lifeline for the people and aquatic wildlife. However, it faces numerous challenges such as water abstraction and pollution, underscoring the urgent need for dedicated conservation efforts.

I commend the extraordinary work done by National River Conservation Directorate (NRCD) and the Wildlife Institute of India (WII) in highlighting ecological status of Indian rivers, hotspots and the road map for their conservation. This report prepared under the project "Assessment of ecological status of select Indian rivers for conservation planning, with the support from NRCD involves meticulous scientific research and provided invaluable insights towards ecological health of the river. The findings of the report are crucial in shaping effective conservation strategies to conserve and restore the river diverse ecosystems.

I firmly believe that the success of this project should inspire similar initiatives across other rivers in India. By adopting a collaborative and scientifically informed approach, we can address the ecological challenges faced by our river systems and ensure their long-term health and sustainability. The conservation of river biodiversity is not just an environmental imperative but a necessity for well-being of our society and future generations. It is imperative that we replicate the success of this project to other rivers across India.

I encourage the continuation and expansion of these vital efforts.

(Dr. Raj Bhushan Chaudhary)

देवश्री मुखर्जी
Debashree Mukherjee
सचिव
SECRETARY

सत्यमेव जयते

भारत सरकार
जल शक्ति मंत्रालय
और गंगा संरक्षण विभाग
GOVERNMENT OF INDIA
MINISTER OF JAL SHAKTI
DEPARTMENT OF WATER RESOURCES,
RIVER DEVELOPMENT & GANGA REJUVENATION

Message

I am pleased to express my appreciation for the outstanding work carried out by the National River Conservation Directorate (NRCD), Department of Water Resources, River Development & Ganga Rejuvenation, Ministry of Jal Shakti and the Wildlife Institute of India (WII), Dehradun for conducting ecological assessment of select Indian rivers for conservation planning. This study represents a pioneering effort in river conservation planning for Indian rivers and should be recognized as a landmark achievement in our river conservation efforts. Such initiatives set a strong foundation for future endeavours in preserving our Indian rivers.

In the past, our conservation efforts were largely directed to terrestrial conservation. After creation of Ministry of Jal Shakti, Government of India, this is first kind for developing baseline on river biodiversity for planning water resource development in future.

I congratulate the joint efforts of NRCD and WII, for undertaking this important work. As one of the flagship projects of the Ministry of Jal Shakti, this initiative highlights our commitment to sustainable water resource management. I am confident that the success of this project will inspire further advancements in river conservation across the country.

The journey to assess river biodiversity does not end here. Continuous monitoring and reassessment would be required to understand the evolving status of our rivers. It is crucial to periodically revisit our conservation strategies to ensure their effectiveness and to adapt new challenges.

(Debashree Mukherjee)

राजीव कुमार मित्तल, भा.प्र.से.
परियोजना निदेशक
राष्ट्रीय नदी संरक्षण निदेशालय
Rajeev Kumar Mital, IAS
PROJECT DIRECTOR
NATIONAL RIVER CONSERVATION DIRECTORATE

भारत सरकार
जल शक्ति मंत्री
जल संसाधन
नदी विकास एवं गंगा संरक्षण विभाग
Government of India
Minister of Jal Shakti
Department of Water Resources
River Development and Ganga Rejuvenation

Message

Rivers in India are the vital lifeline, playing crucial role in sustaining both the natural environment and local communities. However, this precious resource is increasingly threatened by various human activities such as dam construction, water abstraction, sewage and industrial effluent discharge, and the sprouting population of invasive species, all of which affecting survival of aquatic wildlife and livelihood of local communities.

I am immensely proud of the comprehensive assessment conducted by the Wildlife Institute of India (WII), Dehradun on the ecological status of rivers in India. This critical work, aimed at conservation planning, provides us with an in-depth understanding of the current state of our rivers and its biodiversity. The conservation actions suggested in this report are invaluable for conserving and rejuvenating our river ecosystems.

The success of the project underscores the importance of scientific research and collaborative efforts in ecological conservation. By adopting a scientific and community-centric approach, we can ensure the long-term health and sustainability of our rivers.

The conservation of river biodiversity is not just an environmental imperative but a necessity for the well-being of our society and future generations. It is the need of the hour to replicate success of this project to other rivers across India. Such initiatives are essential for restoring and maintaining ecological balance of our river ecosystems. I wish NRCD team to continue such efforts.

(Rajeev Kumar Mital)

प्रदीप कुमार अग्रवाल, भा.प्र.से.
Pradeep Kumar Agrawal, IAS
संयुक्त सचिव
Joint Secretary

सत्यमेव जयते

भारत सरकार
जल शक्ति मंत्रालय
जल संसाधन, नदी विकास एवं गंगा संरक्षण
GOVERNMENT OF INDIA
MINISTER OF JAL SHAKTI
DEPARTMENT OF WATER RESOURCES,
RIVER DEVELOPMENT & GANGA REJUVENATION

Message

Rivers in India are threatened with dam construction, water abstraction, sewage and industrial effluent discharge, and the sprouting population of invasive species. These activities jeopardize the survival of diverse wildlife and the livelihoods of local communities.

Recognizing the critical state of our rivers, the Wildlife Institute of India (WII), Dehradun with the support of the National River Conservation Directorate (NRCD) has undertaken a study for comprehensive assessment of the ecological status of select Indian rivers which aims at in-depth understanding of the current health of our river ecosystems and the biodiversity they support.

The findings of this study are invaluable, offering detailed insights into the ecological challenges faced by our rivers. The WII has not only identified the issues but also suggested effective mitigation measures to protect and rejuvenate these vital waterways. The recommended conservation actions are crucial for maintaining the ecological balance and ensuring the sustainability of our river ecosystems.

The success of this project underscores the importance of scientific research and collaborative efforts in river conservation. By adopting a scientific and community-centric approach, we can address the challenges faced by our rivers and work towards their long-term health and sustainability. I commend WII - NRCD for their dedicated efforts in assessing the ecological status of our rivers and for providing a roadmap for their conservation.

(Pradeep Kumar Agrawal)

CONTENTS

05

Floral assemblage

06

Ichthyofauna

07

Herpetofauna

08

Avifauna

09

Mammals

10

Anthropogenic pressures

11

Genetic Diversity and Gene Flow

12

Conservation Priority Stretches

13

Conclusion and Recommendations

14

Appendices

EXECUTIVE SUMMARY

THE GODAVARI RIVER, ALSO REFERRED TO AS THE 'GANGES OF SOUTH INDIA' OR 'DAKSHIN GANGA,' HOLDS SIGNIFICANT ECOLOGICAL, SOCIAL, CULTURAL, AND HISTORICAL IMPORTANCE. ORIGINATING NEAR TRIMBAKESHWAR IN MAHARASHTRA'S NASHIK DISTRICT, AT AN ELEVATION OF 1,067 M ABOVE MEAN SEA LEVEL, IT COURSES APPROXIMATELY 1,465 KM EASTWARD, TRAVERSING FROM THE WESTERN GHATS ACROSS THE DECCAN PLATEAU BEFORE JOINING THE BAY OF BENGAL. THE GODAVARI BASIN SPREADS OVER THE ADMINISTRATIVE JURISDICTION OF 55 DISTRICTS IN EIGHT STATES VIZ., MAHARASHTRA, TELANGANA, ANDHRA PRADESH, CHHATTISGARH, ODISHA, MADHYA PRADESH, KARNATAKA, AND PUDUCHERRY COVERING NEARLY 10% OF THE GEOGRAPHICAL AREA OF THE COUNTRY. THE PRESENT STUDY WAS CONDUCTED WITH THE OBJECTIVES OF ASCERTAINING THE STATUS OF RIVERBANK VEGETATION AND RIVERINE ANIMAL SPECIES SUCH AS FISH, AMPHIBIANS, REPTILES, BIRDS, AND MAMMALS INHABITING THE GODAVARI RIVER OR POTENTIALLY UTILIZING RIPARIAN ZONE, ALONG WITH EVALUATING ANTHROPOGENIC PRESSURES AND HEAVY METAL POLLUTION. THE ECOLOGICAL ASSESSMENT WAS CARRIED OUT IN THE GODAVARI RIVERSCAPE COVERING THE MAIN CHANNEL, HIGH FLOOD ZONE, AND RIVER BANKS ALONG THE ENTIRE LENGTH OF THE RIVER FROM ITS SOURCE TO THE BAY OF BENGAL.

Following the literature review on the status of the River and its biodiversity, a reconnaissance of the Godavari River was conducted from December 2021 to January 2022, to obtain an initial understanding of the River and its adjacent landscapes. Further, using geomorphological features and the elevation profile, the entire River was characterized into three distinct zones i.e., upper zone (692 km, source to Manjra confluence), middle zone (319 Km, Manjra River confluence to Pranhita River confluence), and lower zone (454 km, Pranhita River confluence to mouth). A total of 29 sampling segments (5 km length each) were identified, which included 14 segments in the upper zone, 5 segments in the middle zone, and 11 segments in the lower zone. Each segment includes three transects of 1 km in length. Subsequently, two rapid assessments of the river were conducted to examine the current status of the River, the status of various taxa, the distribution of species of conservation significance vis-a-vis habitat conditions, water quality, and anthropogenic pressures that affect the integrity of the river ecosystem. The first assessment was conducted in the pre-monsoon season during July and October 2022. This survey primarily focused on the river bank vegetation, fish populations, herpetofauna, birds, and the otters. The second assessment was carried out post-monsoon during December 2022 and March 2023. The biodiversity, river characteristics, anthropogenic pressures, and pollution assessment data obtained through field surveys were used to identify conservation priority areas and biological hotspots in the Godavari River.

The riparian vegetation was assessed using the circular plot method. A total of 242 plant species, including 64 trees (26.4%), 20 shrubs (8.2%), 101 herbs (41%), 25 grasses (10.3%) 28 climbers (11.5%), and 4 sedges (1.6%) were recorded from the Godavari River. 25% of plants were exotic with the majority of them from Tropical America. The average density of trees, shrubs, herbs, grasses, climber and sedges was 98.50 ±4.11 indi/ha, 88.88 ±5.29 indi/ha, 7698.48 ±115.13 indi/ha, 2341.23 ±63.47 indi/ha, 182.37 ±21.03 indi/ha and 77.05±21.97 indi/ha, respectively. *Prosopis juliflora* was the most dominant species among the trees, *Lantana camara* among the shrubs, *Alternanthera sessilis* among herbs, *Cynodon dactylon* among the grasses, *Clitoria ternatea* among the climbers, and *Cyperus rotundus* among the sedges. The trees in the Godavari River sustain an average above-ground biomass per hectare of 6.98 ±0.53 mg.

The fish survey using gill/cast net methods identified 60 fish species representing 15 families and 11 orders with a diversity value of 1.76 and an abundance of 4.88 fish/hour. Family Cyprinidae was the dominant (27 species), followed by Danionidae (seven species) and Bagridae (six species). Three Vulnerable fish species viz., *Oreochromis mossambicus, Cyprinus carpio, Wallago attu*, as well as two Near Threatened fish species, viz., *Ompok bimaculatus* and *Chitala chitala* were recorded during the survey. Five species viz., *Cyprinus carpio, Hypophthalmicthys nobilis, Oreochromis mossambicus, Oreochromis niloticus*, and *Pygocentrus nattereri* were exotic/ invasive to the Godavari River. Correspondence Canonical Analysis (CCA) indicated a positive correlation of fish abundance with turbidity, width, pH, and depth, while negatively associated with conductivity, TDS, boulder, and pebble substrate. The herpetofauna are vital components of the riverine ecosystem. A total of 17 species of herpetofauna, which include 12 species of anurans and five species of reptiles, were recorded from the Godavari River. Amphibians and reptiles were recorded at a diversity of 1.79 and 1.61, respectively.

A total of 210 species of birds were recorded with a diversity value of 4.16. Of the total species recorded in the Godavari River, 55% (116 species) were terrestrial, 36% (76 species) were waterbirds and 8.5% (18 species) were water-dependent/associate species. Northern pintail (*Anas acuta*), River tern (*Sterna aurantia*), and Northern shoveler (*Spatula clypeata)* were the most abundant species among the waterbirds and Red-vented bulbul (*Pycnonotus cafer*), Asian green bee-eater (*Merops orientalis*), Laughing dove (*Spilopelia senegalensis*) were the frequently sighted species among the terrestrial birds. Among the recorded species, three were endangered, two were vulnerable and eight were near threatened species. Of the recorded bird species, 23 are listed in Schedule I of the Wild Life (Protection) Act, 1972. Fourteen species of mammals were recorded through direct and indirect sightings. All recorded species were terrestrial. Family Cercopithecidae, Herpestidae, and Sciuridae were represented by two species, and other families, Bovidae, Canidae, Felidae, Herpestidae, Pteropodidae, Leporidae Suidae and Viverridae were represented by one species each. One species viz., Blackbuck listed as Schedule I of the Wild Life (Protection) Act, 1972.

Godavari River faces a multitude of anthropogenic disturbances such as water abstraction, waste disposal, sand mining, intensive fishing activities, grazing by domestic livestock, bathing ghats, religious activities, developmental projects, cremation, aquatic vegetation extraction, and brick kilns on the banks. Activities such as fishing pose a threat to aquatic species, potentially impacting their populations. Mining activities can lead to habitat destruction and water quality degradation, adversely affecting both flora and fauna. Unregulated grazing may contribute to soil erosion and habitat disruption, further compromising the delicate balance of the ecosystem. Furthermore, Godavari River, is significantly impacted by industrial activity along its course. Industrial pollution significantly contributes to environmental contamination, including both heavy metal pollution and endocrine-disrupting chemicals (EDCs) pollution. In the present study, physiochemical parameters such as pH, Conductivity, Salinity, Nitrate, and TDS were higher than the recommended limits of USEPA Aquatic Life Quality Criteria. Among the recorded heavy metals in the water of the Godavari River, the concentrations of zinc, mercury, lead, and cadmium exceeded the permissible levels as well, and the concentration of chromium in sediment was found to be higher than the permissible limits set by international standards. Additionally, EDCs compounds such as PAEs (Phthalate esters), OCPs (Organochlorine pesticides), OPs (Organophosphorus Pesticides), Pyrethroid, Pharmaceuticals, BPA (Bisphenol A), Hormones, HPCP (Health and personal care products) were detected in both water and sediment. The bioaccumulation profile showed accumulation of PAEs, followed by Zn, BPA, OCPs, and Cr, indicating their persistence and potential risks to human health through consumption of contaminated aquatic organisms.

Genetic assessment was done to assess the impact of dams or other water control structures on the genetic diversity and gene flow of fish species in the Godavari River. High mitochondrial genetic diversity was detected in *Wallago attu, Puntius sophore* and *Devario aequipinnatus,* while *Garra mullya* exhibited low mitochondrial genetic diversity. Microsatellite analyses showed moderate level of observed heterozygosity, with low genetic differentiation (Fst =0.03) in *Wallago attu*. Asymmetrical migration rates were observed in *Wallago attu* populations, with low migration between upper and middle zones of the river.

Using ecological niche modeling, conservation priority stretches have been delineated in areas that provide habitat for various taxa. A total of 225 km of the Godavari River, including 26 km upper zone (Sangvi to Kanhegaon, Ahmednagar), 84 km in middle and lower zone (Medipalli coalmine, Pedapalli to Medigadda barrage, Jayashankar), and 115 km in lower zone (Iravendi Temple to Singalapalle, East and West Godavari) were found to have suitable habitats for multiple species. Among these, 40 km river stretch protected under Papikonda National Park, while remaining river stretch unprotected.

In conclusion, the Godavari River has a low richness of trees and shrubs and as far as the fauna was concerned, the River sustains a high richness of amphibians, waterbirds as well as terrestrial birds, a moderate richness of fish and low richness of reptiles. The presence of the 61 exotic vegetation along with the dominance of *Prosopis juliflora* among trees, *Lantana camara* among shrubs and *Alternanthera sessilis* among herbs indicated a predominance of invasive and exotic vegetation along the river. Five invasive fish species viz., *Cyprinus carpio, Hypophthalmicthys nobilis, Oreochromis mossambicus, Oreochromis niloticus*, and *Pygocentrus nattereri* occur in the Godavari River.

Though Godavari River supports a low abundance of flora and fauna, it is home to species of conservation concern. The presence of threatened and near-threatened species, including those categorized under Schedule I of the Wild Life (Protection) Act, 1972, accentuates the ecological importance of this River. The various species of conservation significance include endangered birds such as Black-bellied tern (*Sterna acuticauda*), Indian skimmer (*Rynchops albicollis*), Great Knot (*Calidris tenuirostris*), vulnerable birds such as Common pochard (*Aythya ferina*), River Tern (*Sterna aurantia*) and near threatened birds such as Grey-headed fish-eagle (*Icthyophaga ichthyaetus*), Woolly-necked stork (*Ciconia episcopus*), Painted stork (*Mycteria leucocephala*), Black-tailed godwit (*Limosa limosa*), Alexandrine parakeet (*Psittacula eupatria*), Oriental darter (*Anhinga melanogaster*) and Black-headed ibis (*Threskiornis melanocephalus*). Blackbuck (*Antilope cervicapra*) a schedule I species is found along the Godavari River. This indicates that the Godavari River is vital for the conservation of various globally threatened species.

The Godavari River can be sustained through effective conservation management. It is suggested to form a confederation of institutions from the states of Maharashtra, Telangana, and Andhra Pradesh with support from the National River Conservation Directorate (NRCD) so as to effectively manage the river's resources and promote data sharing, research, and effective policy implementation. This confederation of institutions would serve as a central body to coordinate information, research, and updates among various agencies, research institutions, and stakeholders. It would support effective decision-making, policy formulation, and the sustainable management and conservation of the river by fostering collaboration and aligning with national and state policies. The study suggests that the ecological values of the Godavari River can be sustained through following measures

- It is proposed that bringing the identified conservation priority stretches, i.e., about 225 km of the river stretch, including 26 km in the upper zone, 84 km in the middle zone, and 115 km (40 km protected under Papikonda National Park) in the lower zone under the regulatory framework of the Wild Life (Protection) Act, 1972 or Other Effective Area-Based Conservation Measures (OECM). Restoring the identified moderately suitable stretches for biodiversity protection through conservation activities.
- Spatial mapping and interpolation have identified polluted stretches of 390.87 km (26.7%) in the river as a heavy metal hotspot in water, while 300.86 km (20.5%) is contaminated in sediment, indicating long-term accumulation risks. Similarly, 102.34 km (7%) of the river is affected by EDCs in water, while 399.47 km (27.3%) is identified as an EDC hotspot in sediment, highlighting persistent contamination concerns. Certain stretches need ecological restoration through active monitoring, inspecting, and imposing penalties for unauthorized industrial discharge. Monitoring and diverting the domestic sewage channels/Nallahs to STPs at Nashik, Gangakhed City, and the stretch between Rayanpeta and Rajahmundry in Andhra Pradesh.

- Monitoring and reducing the use of pesticides by organizing training on Integrated Pest Management at the grassroots level through farmer-filled schools (FFSC) and promoting organic farming in the Godavari riverscape. Promoting sustainable and improved practices for waste management through collection, segregation, and treatment of solid wastes all along the river, at least in urban areas may reduce pollution load in the River.
- The Godavari River is fragmented by 26 dams, constructed mainly for irrigation, and hydroelectricity. The Water Resources Department of the respective states should ensure a minimum environmental flow of 25-30% of the average lean season flow in the Godavari River following the direction of the National Green Tribunal (NGT), the River and Canal Act 1863, and the Minimum Water Flow Protection Act, 1977 through active management and restricting unauthorized abstraction practices to safeguard the flow regimes and riparian biodiversity of Godavari.
- Creating sentiments among the local communities for Godavari River conservation through awareness, creating amusement parks and involving them in the celebration of the various national level initiatives such as Nadi Utsav, Swachh Bharat Abhiyan, Mission LiFE (Mission Lifestyle for Environment) under Green Credit Programme (GCP), 2023.

01 BACKGROUND

India has about 4% of the world's renewable freshwater reserve, which supports nearly 18% of the world's population and a unique assemblage of aquatic and semi-aquatic biota. The perennial and rain-fed rivers are crucial water resources and habitats for humans and biodiversity in the country. CWC has come up with 20 river basins comprising of 12 major river basins and 8 composite basins using Survey of India (SOI) toposheets and contour maps. These rivers are Indus, Ganga and Brahmaputra originating from the Himalaya-Karakoram ranges; the Narmada River from the Aravalli range; Mahanadi River from the Chota Nagpur plateau; and Godavari, Krishna, and Cauvery from the Western Ghats. Brahmaputra - Barak - Ganga System accounts for about 60% of the total surface water resources of India (NIH, 2019).

The Rivers in India pass through the nine biogeographic zones and nurture unique aquatic species assemblance. However, due to increasing demand for domestic, industrial, and agricultural uses, most of these river basins are water-stressed. The impoundments have altered the natural flow regime of most of the rivers and subsequently reduced the carrying capacity to drain off the pollutants. This is further accentuated by the fact that around 61,948 million liters per day (MLD) of sewage is being generated from Class I and Class II cities in and around these river basins and only 37% of the sewage is treated before being drained (CPCB, 2015). Out of the total measurable pollution in the rivers from various point sources, around 75% is accounted for by municipal sewage from towns located along the banks of rivers, and the remaining 25% is accounted for by industrial effluents. In addition, micro- and macro-plastics, persistent xenobiotics, EDSs pose toxicological risks to the rivers (Moore, 2006).

In India, 5264 completed large dams are fragmenting most major rivers and their tributaries, with an additional 437 dams under construction (CDSO, 2019). In the Ganga basin alone, 795 dams and 181 barrages and weirs (Water Resource Information System, 2019) are altering the physical habitat and making the rivers intermittent. An estimated 70.7% of the Bhagirathi River and 48% of the stretch of the Alaknanda River in the Ganga basin have been morphologically altered. Almost 90% of the water is extracted from the Bhimgoda barrage reducing flow downstream till the confluence of the Yamuna River and limiting the distribution of Gangetic dolphins (WII-GACMC, 2018). Large multipurpose dams in peninsular rivers such as Narmada, Godavari, Krishna, and Cauvery are impacting aquatic species and their habitat. Habitat fragmentation in the Narmada River has created genetic differentiation in the *Mastacembelus armatus* population (Khedkar et al., 2014). Dams in the Krishna and Cauvery headwaters in the Western Ghats have adversely impacted the population of endemic species (Naniwadekar and Vasudevan, 2014). The construction of dams on the Godavari and Krishna

rivers has resulted in the retention of sediment, in turn, affects the deltas by depriving them of sediments in the delta-building process, which leads to shoreline erosion rather than accretion (Rao et al., 2010).

India is mostly arid or semi-arid, and climate change is a crucial concern for the resources of the country (IPCC, 2001). Hence, existing threats to rivers will be heightened by the impacts of climate change and altered water quality, questioning the survival of the aquatic species (Bouwer and Aerts, 2006). Additionally, the absence of policies and institutional mechanisms at the state basin level, or the larger basin level, and those on water resource development and water allocation, taking into consideration the ecological health of rivers is a critical concern (Amrit et al., 2018). As a consequence of the synergistic impact of these factors, the freshwater biota of these river basins is under stress and some have become locally extinct. Restoring degraded waterways and ensuring their ecological integrity is a complex and challenging endeavor. However, restoration efforts should prioritize maximizing natural processes while addressing current human priorities. Although numerous studies have been carried out on Indian rivers, these studies are fragmented. Moreover, studies on aquatic species diversity, richness, and their functional roles to draw any conclusion about the ecological status of the river for conservation planning are lacking. Hence, the ecological considerations during river regulation, water abstraction, and morphological modification are less accounted for while planning developmental projects.

In this regard, a consultative meeting was held at the National River Conservation Directorate (NRCD), Ministry of Jal Shakti to identify the major Indian rivers for conservation prioritization on 16th December 2019. The meeting was chaired by Smt. T. Rajeswari, Additional Secretary, Ministry of Jal Shakti and co-chaired by Mr B. B. Barman, Advisor, NRCD. The meeting was attended by representatives from the National Mission for Clean Ganga (NMCG), International Union for Conservation of Nature (IUCN), Zoological Survey of India (ZSI), Wildlife Institute of India (WII), Central Water Commission (CWC), and Forest Research Institute (FRI). It was suggested that the Biodiversity Conservation and Ganga Rejuvenation model implemented by the Wildlife Institute of India under the National Mission for Clean Ganga project should be replicated to start the nationwide river conservation project, and WII can be the nodal agency. A comprehensive set of criteria was recommended to prioritize rivers for condition assessment. To begin with, the following criteria were agreed upon, viz., 1. Socio-cultural value, 2. Biodiversity value, 3. Pollution load, 4. The extent of modification of river morphology, and 5. Biogeographic zones. It was proposed that Cauvery, Godavari, Periyar, Mahanadi, and Narmada should be taken as priority rivers as suggested by His Excellency Ram Nath Kovind, President of India, in the Parliament. Successively, the Wildlife Institute of India submitted a proposal for systematic conservation planning of select rivers in India, and a detailed work plan of the proposed project was presented during a follow-up meeting held on 14th February 2020 in the office of the National Mission for Clean Ganga (NMCG), under the chairmanship of Director General (DG), NMCG. To cover the northeast states, the least studied Barak River was included in the proposal. Subsequently, on the request of the Government of Kerala, the Pamba River was included in the proposal as it is both biologically and culturally significant for the Kerala State (Figure 1.1, Table 1.1).

Accordingly, a project entitled "Assessment of the status of select Indian rivers for conservation planning" was given to WII for implementation by the National River Conservation Directorate (NRCD), Ministry of Jal Shakti, Government of India, New Delhi. The project aimed to assess the status of riverbank vegetation, fish species, reptiles, birds, and aquatic mammals, including a focus on the status of threatened flora and fauna for conservation planning. The study also encompasses the water quality, eco-toxicological assessment, and examination of the genetic diversity and gene flow of the select macrofauna of the identified rivers.

1.1 Aim

This project aimed to spearhead river conservation in the identified Indian rivers for biodiversity conservation and sustainable use of water resources. The major objectives are to:

1.2 Objectives

- Prepare the biodiversity profile of the identified rivers to derive the current ecological status.
- Identify direct and indirect drivers affecting the integrity of these rivers.
- Assess the concentration of key pollutants such as micro and macro-plastics, pesticides, heavy metals, and other endocrine disruptive substances (EDCs) in the identified rivers and bioaccumulation in species of conservation concern.
- Derive the current trend in genetic variability and gene flow of identified species that might have been disrupted due to river fragmentation.
- Identify conservation priority zones and prepare a conservation action plan for select stretches to minimize the negative impact of the direct and indirect drivers on river ecosystem processes.
- Identify, prioritize, and enhance the capacity of the regional institutions/organizations for long-term involvement in river conservation.
- Strengthen the existing Ganga Aqua Labs at WII to cater to the requirements of other Indian rivers for conservation planning and information dissemination.

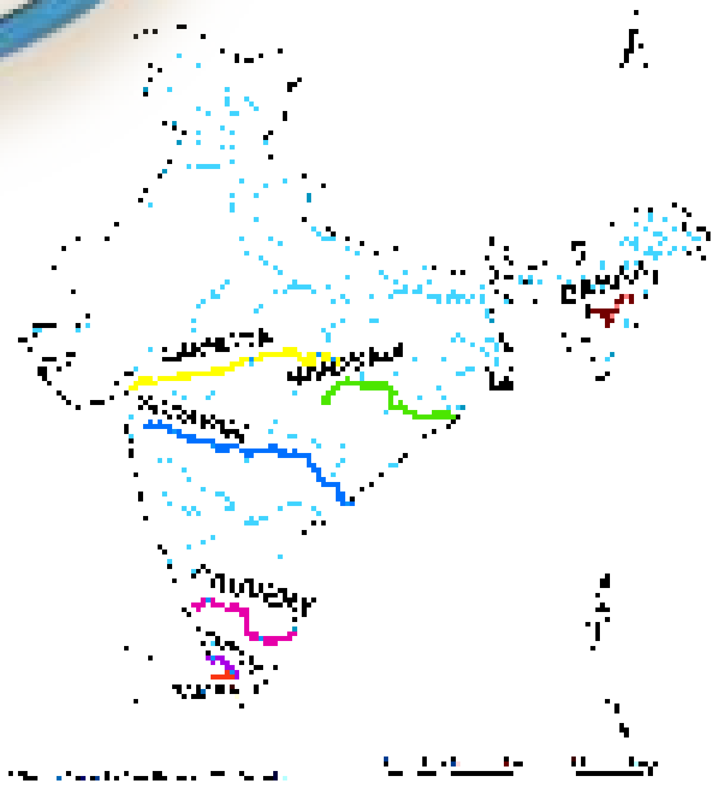


Figure 1.1 Rivers under the project on "Assessment of the ecological status of select Indian rivers for conservation planning"

Table 1.1: Detail of various rivers in the project "Assessment of the status of select Indian rivers for conservation planning"

Rivers	State/ Union Territory	Biogeographic Zone	Length (km)	Discharge (m^3/s)	Catchment Area (km^2)
Barak	Meghalaya, Manipur, Nagaland, Mizoram, Assam, Tripura	North-East	564 in India	7,786	52,000
Mahanadi	Chhattisgarh, Odisha	Deccan Peninsula - East Coast	850	2,119	1,41,589
Narmada	Gujarat, Madhya Pradesh, Maharashtra	Semi-arid - Deccan Peninsula, West Coast	1312	1,447	98,796
Godavari	Maharashtra, Telangana, Andhra Pradesh, Chhattisgarh	Western Ghats-deccan Peninsula	1465	3,505	30,14,503
Cauvery	Karnataka, Tamil Nadu	Western Ghats-deccan Peninsula, East Coast	805	677	81,155
Periyar	Kerala	Western Ghats-deccan Peninsula	244	1,364.65	5,398
Pamba	Kerala	Western Ghats	176	109	2235

Figure 1.2 Previous study reports on the ecological status of Godavari River based on literature review and preliminary assessment

With of aforementioned objectives in the mind, a literature review was conducted on the profile of Godavari River, its biodiversity, and direct and indirect threats to the river, conservation issues and research gaps. The review report developed "Godavari Riverscape: Ecological status and trends" was submitted to National River Conservation Directorate, Ministry of Jal Shakti, India on dated 16 September 2022 (Figure 1.2). Following this, a preliminary survey was carried out in the Periyar River to get an overview of the river and its flora and fauna.

Thereafter, an intensive survey of the Periyar River was conducted between October, 2022 and March, 2023 with the following research questions:

- **What is the present status of the Godavari River?**
- **What is the status of biodiversity inhabiting the Godavari River?**
- **What are the direct and indirect threats to Periyar River and its biodiversity?**
- **What are the areas of high biodiversity value?**
- **How to conserve the Godavari River and its biodiversity?**

The present report “Assessment of Ecological Status of Godavari River for Conservation Planning” presents the status of biodiversity inhabiting the Godavari River, conservation priority stretches, and suggestive measures for their long-term conservation.

References

Amrit K, Mishra SK and Pandey R (2018) Tennant concept coupled with standardized precipitation index for environmental flow prediction from rainfall. Journal of Hydrologic Engineering 23(2), 05017031.

Bouwer LM and Aerts JC (2006) Financing climate change adaptation. Disasters 30(1), 49-63.

CDSO (2019) National Register of large dams. Central Water Commission, Dam Safety Monitoring Directorate, Government of India. Central Dam Safety Organization.

CPCB (2015) Air quality database. Central Pollution Control Board, New Delhi.

Houghton JET, Ding Y, Griggs D, Noguer M, Van Der Linden P, Dai X, Maskell M and Johnson C (2001) Climate Change 2001: The Scientific Basis. 881 (9). Cambridge: Cambridge university press.

Khedkar GD, Lutzky S, Rathod S, Kalyankar A and David L (2014) A dual role of dams in fragmentation and support of fish diversity across the Godavari River basin in India. Ecohydrology 7(6), 1560-1573.

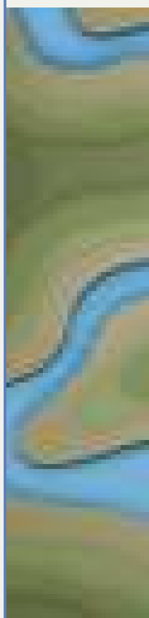
Moore M (2006) Do nanoparticles present ecotoxicological risks for the health of the aquatic environment? Environment International 32(8), 967-976.

Naniwadekar R and Vasudevan K (2014) Impact of Dams on Riparian Frog Communities in the Southern Western Ghats, India. Diversity 6, 567-578.

NIH (2019) Surface Water availability, National Institute of Hydrology, Roorkee.

Rao KN, Subraelu P, Kumar KCVN, Demudu G, Malini BH, Rajawat A and Ajai (2010) Impacts of sediment retention by dams on delta shoreline recession: evidences from the Krishna and Godavari deltas, India. Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group 35(7), 817-827.

WII-GACMC (2018) Macro Fauna of the Ganga River: Status and Conservation of Select species. Ganga Aqualife Conservation Monitoring Centre Wildlife Institute of India, Dehra Dun.Uttarakhand, India.



02

GODAVARI RIVER

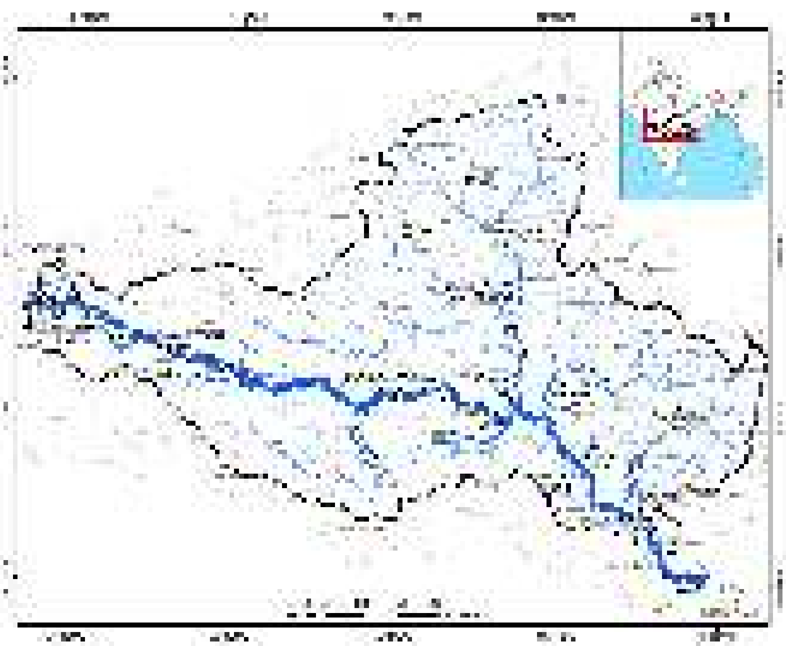
02

GODAVARI RIVER

2.1 Godavari River

Godavari River is the largest and longest river system (1,465 km long) in Peninsular India and is considered the second-longest river in the country after the Ganges. It rises near Trimbakeshwar in the Nashik district in Maharashtra at an altitude of 1,067 m AMSL, traverses east from the Western Ghats across the Deccan Plateau, and empties into the Bay of Bengal. It is important for nearly 98 million people in the country who are directly or indirectly dependent on the river and its tributaries for their livelihood needs. Thirteen (13) km stretch of the Godavari River traverses through Nashik City of which, about 1.25 km stretch is of religious significance. Kumbh Mela is a mass Hindu pilgrimage in which millions of pilgrims gather on the banks of Godavari in Nashik city to bath in the sacred river. It is one of the world's largest religious gatherings which happens every 12 years. The Godavari basin spreads over the states of Maharashtra, Telangana, Andhra Pradesh, Chhattisgarh, and Odisha, in addition to smaller parts in Madhya Pradesh, Karnataka, and Puducherry covering nearly 10% of the geographical area of the country. It forms the inter-State boundary between the States of Telangana and Maharashtra; and Telangana and Chhattisgarh (Figure 2.1).

Figure 2.1 Location of Godavari River



2.1.1 Origin and Course

The Godavari River rises in the Sahyadris, near Trimbakeshwar in the Nashik district in Maharashtra at an altitude of 1,067 m AMSL, and traverse through Maharashtra, Telangana, and Andhra Pradesh, flowing through the Deccan Plateau from the Western to the Eastern Ghats. The river traverses for most of its course generally eastward across the broad plateau of the Deccan Peninsular India. After central Maharashtra, it enters northern Telangana state northwest of Nizamabad, continues through a broad valley, and forms a short stretch of Telangana's northeastern border with Maharashtra. The River then turns south-eastward for the last 320 km of its course, flowing through the gap in the Eastern Ghats ranges and across Andhra Pradesh before reaching the Bay of Bengal. At Dowleswaram, the River bifurcates into Gautami and Vasishta, in between which, lies the Godavari Central Delta. The Gautami branch joins the Bay of Bengal flowing through the Yanam enclave of the Union Territory of Puducherry. The delta of the Godavari is of lobate type with a round bulge and many distributaries.

From its source to the Eastern Ghats, the Godavari River flows through gentle, somewhat monotonous terrain, while receiving the Darna, Purna, Manjra, Pranhita, and Indravati rivers. Upon entering the Eastern Ghats region, however, the river flows between steep and precipitous banks, its width contracting until it flows through a deep cleft only 600 feet (180 meters) wide, known as the Gorge. Wooded hills rise almost vertically on either side from the water. Having passed through the Eastern Ghats, the river widens again, traversing wide lowland plains.The low islands in its stream are used to grow a variety of crops, notably tobacco. At that point, the Godavari traverses placidly, just beneath the city of Rajahmundry in Andhra Pradesh.

2.1.2 Channel characteristics, Water flow

A major part of the Godavari basin falls in the Deccan plateau and is surrounded by various hill ranges on all sides which shape the channel characteristics of the Godavari River. The river traverses through the gently sloping Maharashtra Plateau eastward from the Sahyadri range, almost bisecting the plateau. Across the eastern part of Maharashtra in the Vidarbha region, the river traverses through the Nagpur-Wardha plain on the west and the Wainganga valley to the southeast which is rich in vegetation. Further eastward, the river passes through steep gorges in the Eastern Ghats where the channel width is around 180 m. Beyond the mountains, the river opens up into a wide coastal plain where the channel width is several kilometers wide at Dhavaleswaram. The slope gradient towards the coastal floodplains ranges from 0 to 3%.

The annual water flow of the Godavari River varies at different locations. The average annual flow of the Godavari River was 274.29 m^3/sec, 126.54 m^3/sec, and 168.49 m^3/sec during the years 2016, 2017 and 2018, respectively.

2.1.3 Major tributaries

The principle tributaries of the Godavari River are Dharna, Kadwa, Pravara, Purna, Manjra, Penganga, Wardha, Wainganga, Pranhita (combined flow of Wainganga, Penganga, Wardha), Indravati, the Maner, and Sabri. The tributaries that join the Godavari River at its left bank include Dharna, Penganga,

Table 2.1 Tributaries of Godavari River, their origin and length

S. No.	Name of the Tributary	Origin	Confluence distance (km)	Catchment area (km^2)	Length (km)
1	Dharna	Kulang hill	57	389.6	80
2	Kadwa	Sahyadri hills (Dindori taluka)	83	1,664	74
3	Pravara	Sahyadri hills	211	6,537	208
4	Sindphana	Chinchol Hill in Balaghat range	397	237.56	122
5	Manjra	Gaukhadi village in Beed district	694	30,844	724
6	Manair	Rajanna	975	13,106	225
7	Pranhita	The confluence of the Wardha and Wainganga rivers	1,010	61093	721
8	Indravati	Dandakaranya in Kalahandi district	1,060	41,655	535
9	Sabari	Sabari	1,283	20,427	418

Source: India WRIS (2014)

Wainganga, Wardha, Pranhita (conveying the combined waters of Penganga, the Wardha and Wainganga), Pench, Kanhan, Sabari and Indravati. Six important tributaries viz., Pravara, Mula, Sindhaphana, Manjra, Peddavagu, and Maner join the Godavari River at its right bank. The tributaries of the Godavari River are as small as 74 km (Kadwa River) to as long as 724 km (Manjra River). Detail on important tributaries of the Godavari River is highlighted in Table 2.1 and Figure 2.2.

Figure 2.2 Map of important tributaries of the Godavari River

2.2 Godavari basin

The Godavari basin, situated between latitude 16° 16' 00" North and 22° 36' 00" North and longitude 73° 26' 00" East and 83° 07' 00" East spreads over an area of 301941.12 km^2 with a maximum length and width of about 995 km and 583 km, respectively (Central Water Commission, 2014). It spreads over eight states of India viz., Maharashtra, Telangana, Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Odisha, Karnataka and Puducherry. Most of the basin falls within Maharashtra, followed by Andhra Pradesh and Telangana (Figure 2.3).

Administratively, the Godavari River basin comes under the administrative jurisdiction of 55 districts in eight states (Figure 2.4). The Godavari basin is bounded by Satmala hills, the Ajanta range, and the Mahadeo hills in the north, Balaghat and the Mahadeo ranges in the south, Western Ghats in the west, and Eastern Ghats and the Bay of Bengal in the east. The interior part of the Godavari basin lies in the Maharashtra Plateau. The majority of the basin falls within the Deccan plateau in Maharashtra where the elevation is highest at 600 m and gradually slopes down towards the east.

Figure 2.3
Proportion of basin in various states of India

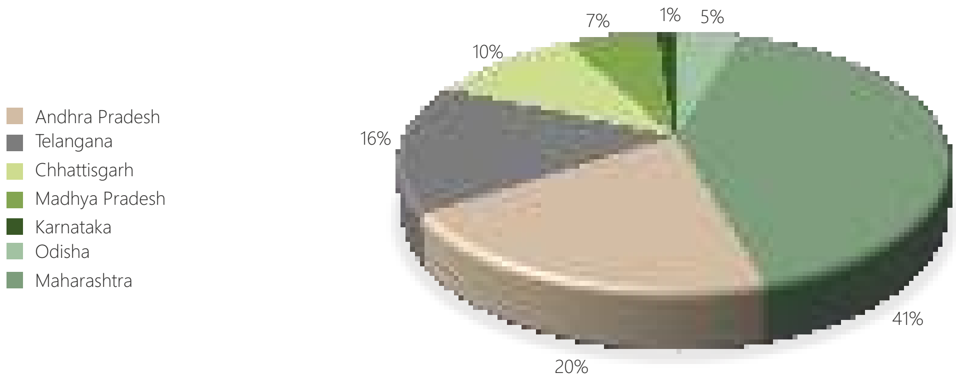


Figure 2.4
Administrative districts in the Godavari basin

2.2.1 Topography

The elevation of the Godavari basin ranges from less than 5 m to 1541 meters and most of the areas of the basin are between 200 and 600 m elevation (Figure 2.5). Godavari Basin is very rugged in the Northeastern part and flat towards the downstream side. The north is bounded by the Mahadeo hills, the Satmala hills comprising a series of table lands varying from 600-1200 m in elevation. The western edge of the basin is bounded by unbroken line of the North Sahyadri range of the Western Ghats, from 600-2100 m in height. In the inner central portion of the basin and the south-eastern part of the Godavari basin, elevation range less than 200 m. The eastern area of the basin is majorly covered by the Dandakaranya Range, with the Eastern Ghats rising from the plains of East Godavari and Vishakhapatnam to the level of the table lands of Jeypore. The southern most boundary of the basin follows the Harishchandra Range in the west, the Balaghat Range in the center, and the Telangana Plateau in the east.

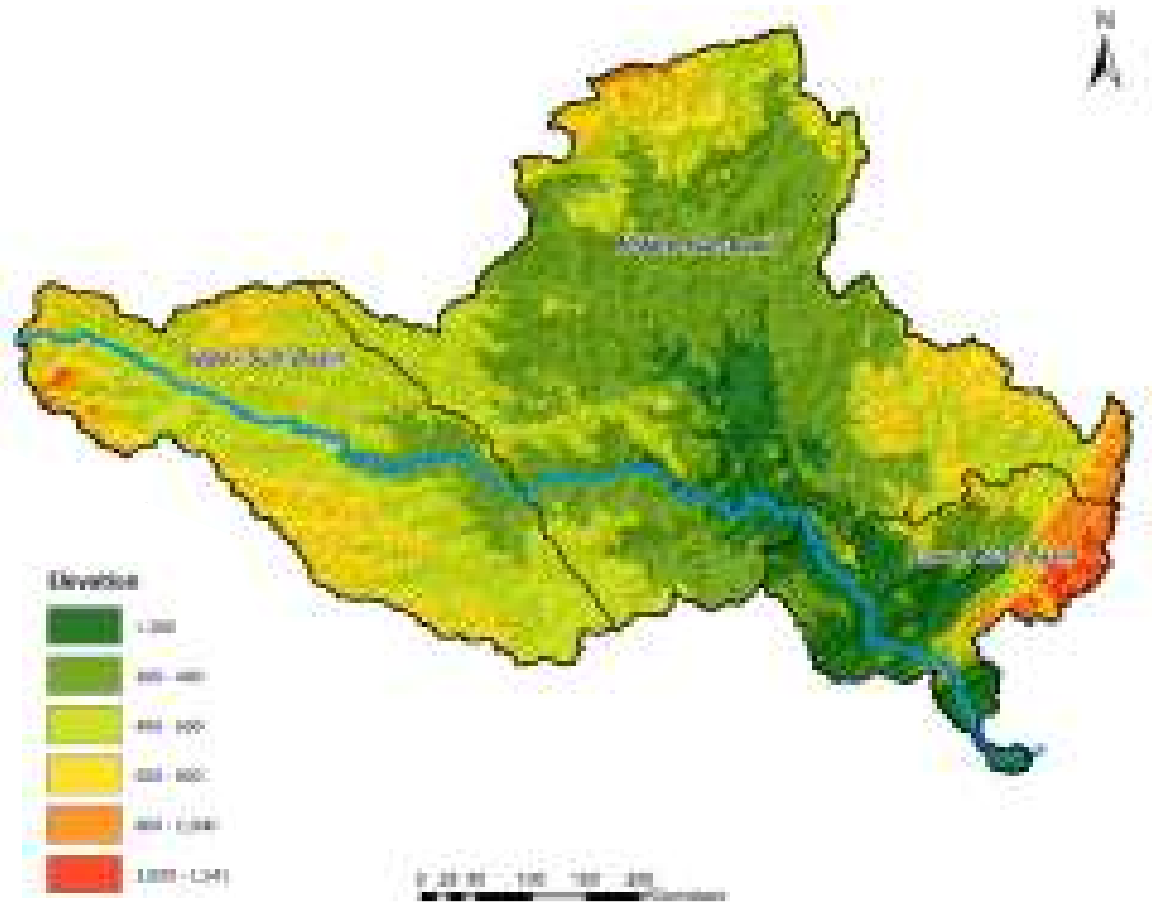


Figure 2.5 Elevation gradients in the Godavari basin

2.2.2 Land use / Land cover

The major part of the basin is covered with agricultural land (1,65,447.25 km^2) accounting for 55% of the total basin area. The basin has a fair forest cover (81,968.74 km^2) and scrubs cover (7,630.55 km^2). A considerable portion of the Godavari basin is under fallow and wasteland (34,958.6 km^2). Waterbodies are the fourth dominant class within the Godavari Basin and it occupies an area of 11,241.57 km^2. Other land-use/land cover classes, such as current fallow, shifting cultivation, grassland, and littoral swamps, and plantations occupy less than 1% of the basin area. Table 2.2 provides information on various land use classes within the Godavari basin. The spatial distribution of various land use classes is shown in Figure 2.6.

Table 2.2 Area under various land use classes in the Godavari basin

Land use/ Land cover category	Godavari Basin (km^2)	Percentage
Built-up	6,708.70	2.16
Agriculture	1,65,447.25	53.37
Current Fallow	17779.16	5.73
Plantation	2,006.35	0.64
Evergreen Forest	101.89	0.03
Deciduous Forest	81,866.85	26.40
Degraded/Scrub Forest	7,630.55	2.46
Wasteland	17,179.44	5.54
Water bodies	11,241.57	3.62
Shifting Cultivation	35.01	0.01
Littoral Swamp	3.42	0.001
Grassland	0.08	0.00
Total	3,10,000.27	100

Source: Computed using ISRO NRSC data, 2012

Figure 2.6 Land use/land cover in the Godavari basin

2.2.3 Biogeography

The Godavari River basin spreads over three important biogeographic zones, namely the Western Ghats, the Deccan peninsula, and the Coasts. Most of the basin is in the Deccan plateau (Figure 2.7). A small stretch of the river (192 km) is in the Western Ghats (Central Water Commission, 2014).

Figure 2.7 Biogeographic zones of the Godavari basin

2.2.4 Forest type and cover

Godavari River encompasses 25 forest types in its basin (Table 2.3, Figure 2.8). 5A/C3 Southern Dry Mixed Deciduous Forest (39,563.65 km^2) is the dominant forest type, followed by 3B/C2 Southern Moist Mixed Deciduous Forest (12,971.17 km^2), 3C/2e (ii) Moist Peninsular Low-Level Sal Forests (6,156.95 km^2) and 5/E4 Hardwickia Forest (0.42 km^2) covering lowest area in the Godavari basin (Table 2.3, Figure 2.8).

The total forest cover in the districts along the Godavari River is 42,414.02 km^2. About 45% of the forest in terms of denseness is represented by moderate forest, 35% by open forest, and the remaining 22% by very dense forest. Gadchiroli (Maharashtra), Bijapur (Chhattisgarh), Khammam, Adilabad (Telangana), and East Godavari (Andhra Pradesh) have the highest forest cover (> 3000 km^2) along the course of Godavari River (Figure 2.9). About 3181.52 km^2 area of the Godavari basin is under the scrub. Scrubland is highest in Karimnagar and Ahmednagar (Figure 2.10).

Table 2.3
Area under various forest types of the Godavari Basin

S. No.	Forest Types	Area (km^2)	Percentage
1	5A/C3 Southern Dry Mixed Deciduous Forest	39563.65	12.74
2	3B/C2 Southern Moist Mixed Deciduous Forest	12971.17	4.18
3	3C/2e (ii) Moist Peninsular Low-Level Sal Forests	6156.95	1.98
4	5A/C1 a Very Dry Teak Forest	5280.58	1.70
5	5A/C1 b Dry Teak Forest	5168.44	1.66
6	3B/C1 c Slightly Moist Teak Forest	4687.34	1.51
7	Water	4416.01	1.42
8	5/DS1 Dry Deciduous Scrub	3085.01	0.99
9	3B/C1 b Moist Teak Forest	3015.25	0.97
10	3C/2e (i) Moist Peninsular High-Level Sal Forests	1075.17	0.35
11	Plantation/TOF	810.82	0.26
12	5/2S1 Secondary Dry Deciduous Forest	639.66	0.21
13	5B/C1 c Dry Peninsular Sal Forest	369.7	0.12
14	6A/C1 Southern Thorn Forest	291.96	0.09
15	5/E5 Butea Forest	163.75	0.05
16	5B/C2 Northern Dry Mixed Deciduous Forest	150.39	0.05
17	5/E9 Dry Bamboo Brake	135.85	0.04
18	3C/2S1 Northern Secondary Moist Mixed Deciduous Forest	69.14	0.02
19	5/E2 Boswellia Forest	68.79	0.02
20	8A/C2 Western Sub Tropical Hill Forest	58.22	0.02
21	3C/2e (iii) Moist Peninsular Valley Sal Forests	13.1	0.00
22	5/DS2 Dry Savannah Forest	12.88	0.00
23	3B/2S1 Southern Secondary Moist Mixed Deciduous Forest	11.76	0.00
24	7/C1 Tropical Dry Evergreen Forest	4.36	0.00
25	5/E4 Hardwickia Forest	0.42	0.00

Figure 2.8
Distribution of various forest types in the Godavari basin

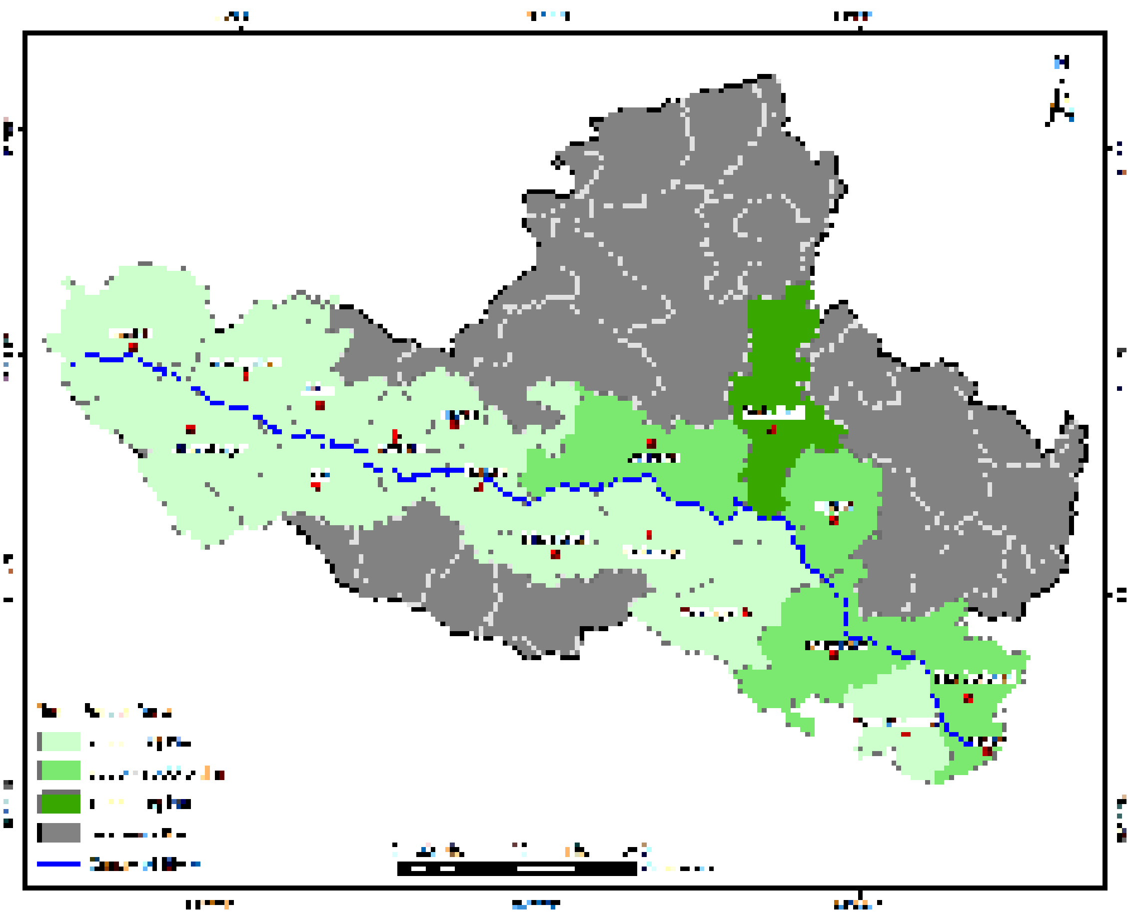


Figure 2.9
Forest cover along the course of the Godavari River

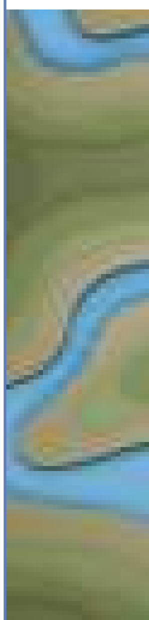
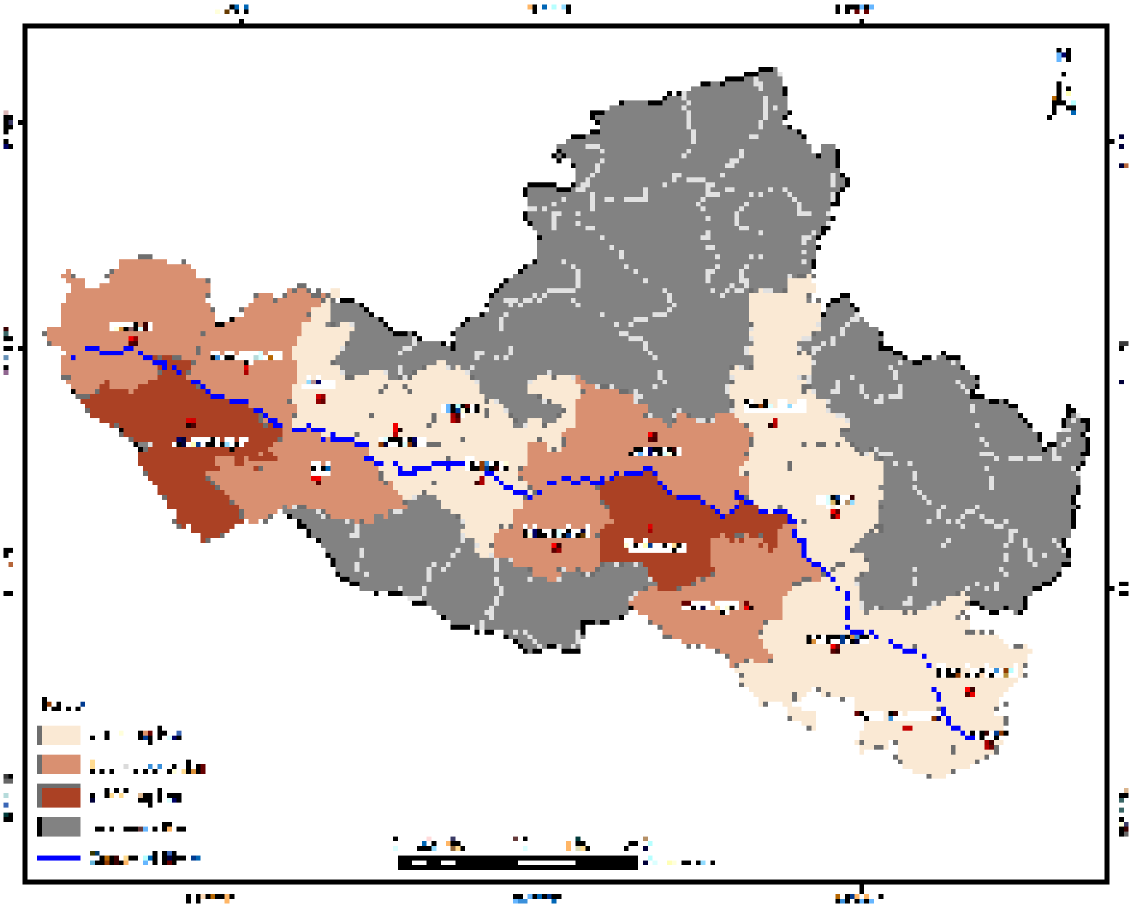


Figure 2.10
Scrub cover along the course of the Godavari River



2.2.5 Demography and human density in the Godavari Basin

The Godavari River basin supports a population of approximately 10,84,18,783 as per the 2011 census (Census of India, 2011), (Figure 2.11). The average density of the population is approximately 290 persons/km^2 (Census of India, 2011). Yanam district of Puducherry is the most densely populated district (1505.84 /km^2) of the basin. The Bijapur district of the Chhattisgarh state has the lowest population density of 30 persons/km^2.

A total of 18 districts are located along the main course of the Godavari River, which includes nine in Maharashtra, five in Telangana, two in Andhra Pradesh, and one in Chhattisgarh and one in Puducherry (Figure 2.12). As per 2011 Census, approximately 4,82,24,911 humans live along the course of the Godavari River. The average human density is about 273 individuals/km^2. East Godavari, Nashik, and Ahilyanagar are the most populated districts along the course of the Godavari River. Nashik and Aurangabad support the highest urban population in the basin (Figure 2.13). East Godavari, Ahilyanagar have the highest rural population (Figure 2.14).

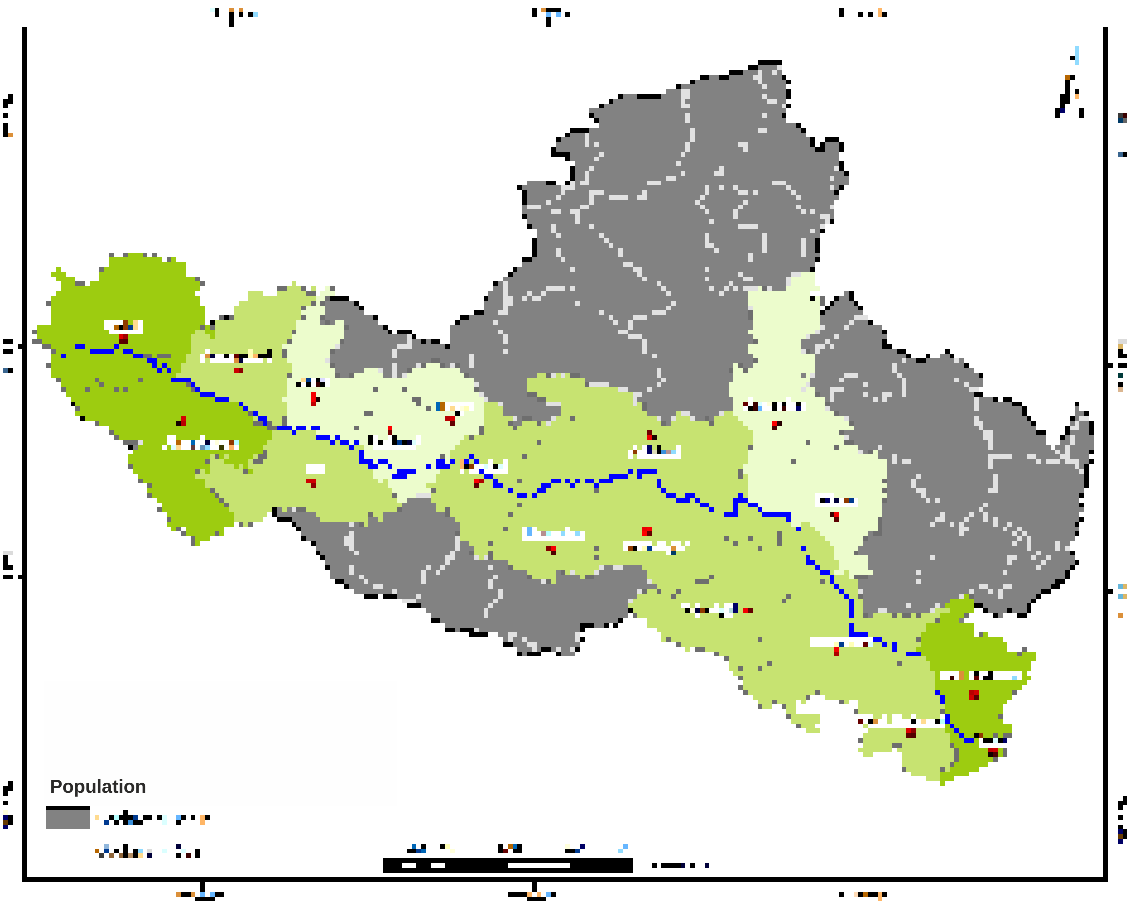


Figure 2.11 Population in various districts along the Godavari River

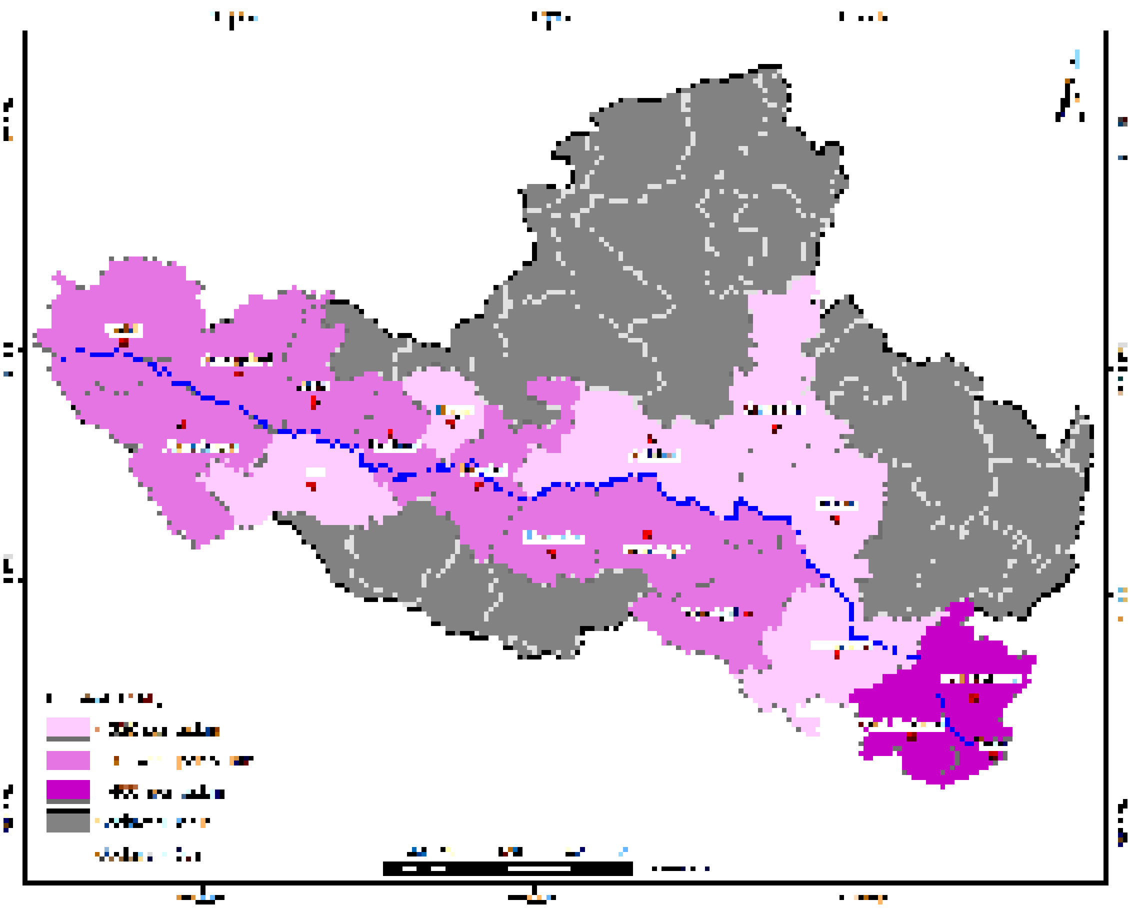
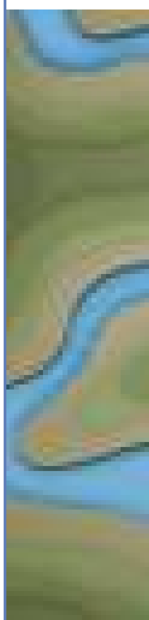


Figure 2.12 Human density in various districts along the Godavari River



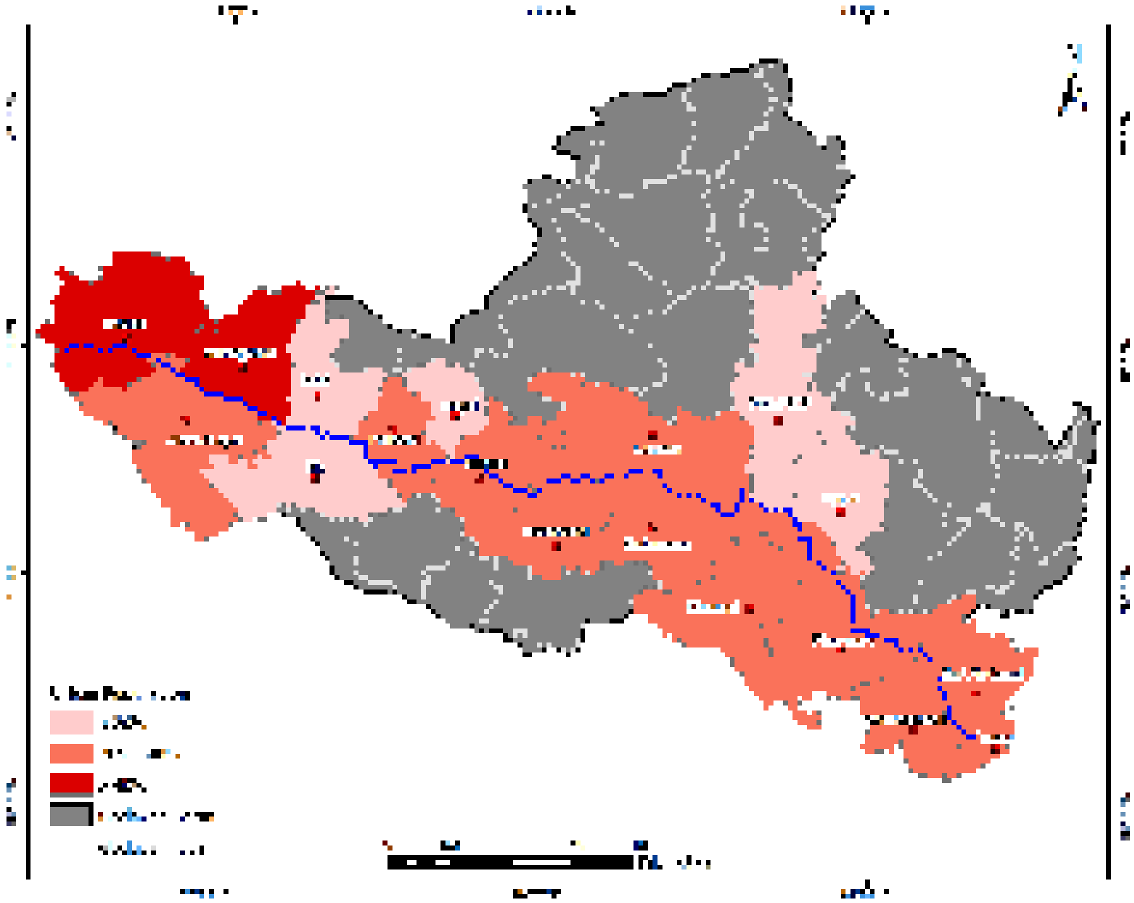


Figure 2.13
Urban population along the course of the Godavari River

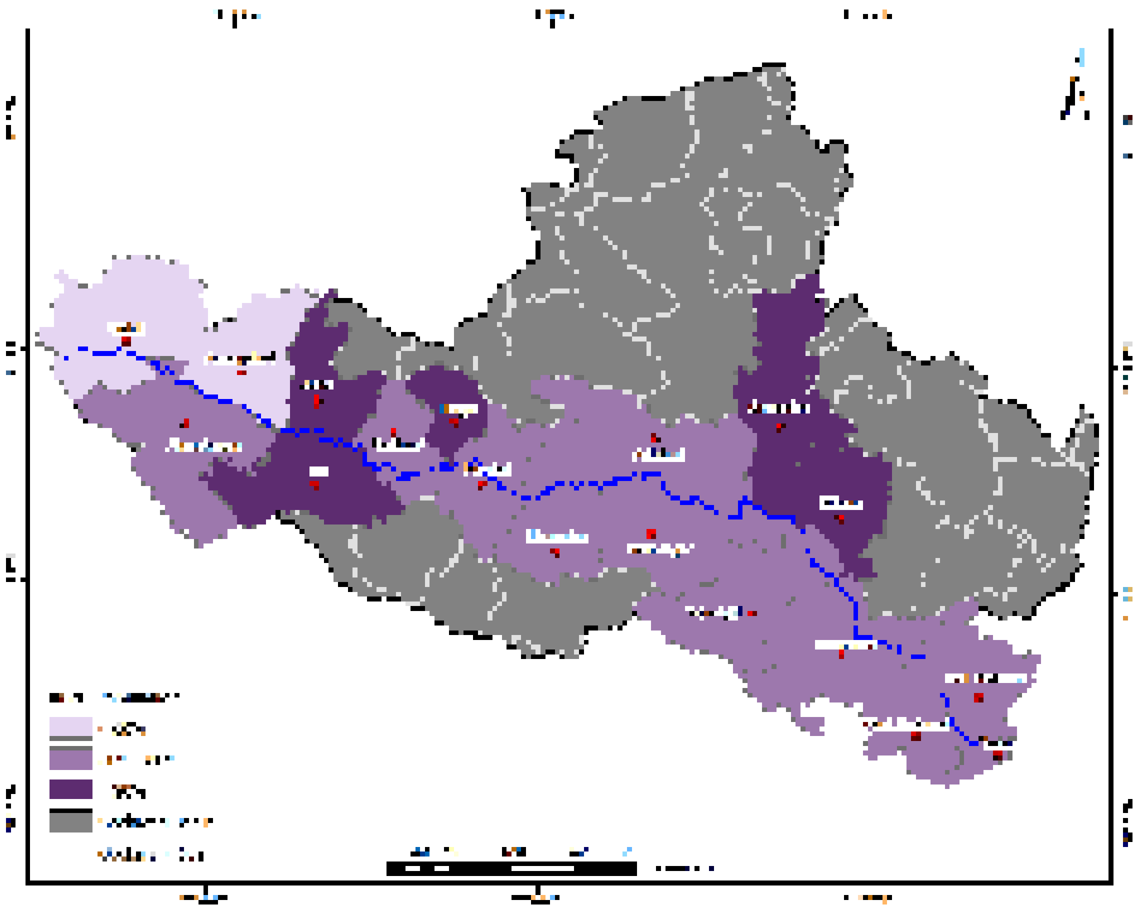
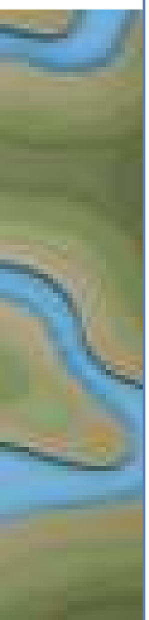


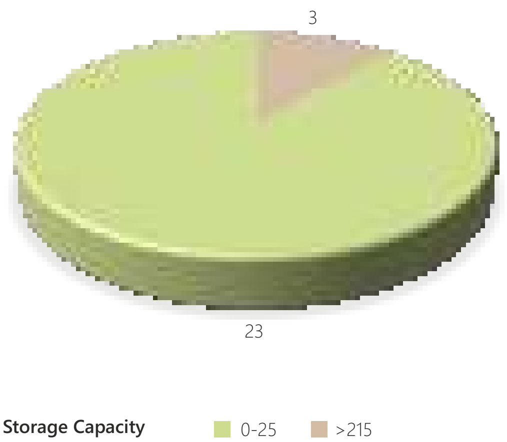
Figure 2.14
Rural population along the course of the Godavari River



2.2.6 Dams on the Godavari River

A total of 26 Dams are present on the Godavari River. These dams were constructed to provide irrigation, hydroelectricity and other facilities in the Godavari Riverscape. The majority of dams (88.46%) have a storage capacity of 0-25 MCM except for three dams viz., Jayakwadi dam in Maharashtra, Sriram Sagar/ Pochampa dam in Telangana, and Pedallareddy dam in Andhra Pradesh have a storage capacity of >215 MCM (Figure 2.15). Major dams in the Godavari Riverscape are Sriramsagar (SRSP)/Pochampad dam, Gosikhurd dam, and Jayakwadi dam. Information on various dams on the Godavari River is provided in Appendix 2.1.

Figure 2.15 The storage capacity of dams in the Godavari River



2.3 Godavari Riverscape

The concept of "Riverscape" (or river landscape) was proposed as early as in 1960s when Leopold and Marchand (1968) used the term to describe the broad-scale physical, biological, and aesthetic nature of rivers. Landscape perspectives in riverine ecology have been undertaken increasingly in the last 30 years, leading aquatic ecologists to develop a diverse set of approaches for conceptualizing, mapping, and understanding "Riverscape". The incorporation of concepts from landscape ecology into understanding and managing riverine ecosystems has become widely known as Riverscape ecology. Riverscapes are complex, interconnected ecosystems consisting of channels, banks, riparian zones, and floodplains Riverine landscape or "Riverscape" approach of river management include the delineation of treatment area based on the understanding of patterns and processes of the river and its banks/riparian areas. As such river landscape is the interface between terrestrial and aquatic ecosystems and should be delineated considering ecological processes, mosaic of landforms, communities, and environment within the large landscape.

Considering the above facts in view and also the diversity, complexity, and intricacies of the Godavari River, an area was delineated as the "Godavari Riverscape" consisting of the area under the main channel, high flood zone, and banks of the river all along the main stem starting from the origin of the river to the Bay of Bengal. This delineated 145 km stretch is the study area of the project for carrying out the proposed ecological studies to devise strategies to conserve the biodiversity of this important river of the country (Figure 2.16). This approach allows for a holistic understanding of the river's ecological and environmental dynamics and emphasizes the interconnectedness of the river with its surrounding landscapes, including the diverse ecosystems and land-use patterns that influence the river's health and sustainability.

Figure 2.16 Godavari River/ study area of the project

References

Central Water Commission (2014) Annual Report 2014-15 Ministry of Water Resources, River Development and Ganga Rejuvenation, Governemntment of India pp.1-195.

Census of India (2011) National Population Register & Socio-Economic and Caste Census India. Office of the Registrar General and Census Commissioner, India

India-WRIS (2014) Godavari basin. Ministry of Water Resources, Government of India. http://www.india-wris.nrsc.gov.in/Publications/BasinReports/Godavari%20Basin.pdf. Accessed 20 Dec 2022

ISRO-NRSC (2012) Manual of National Land Use/Land Cover Mapping (Second Cycle) Using Multi-temporal Satellite Data. Department of Space, Hyderabad.

Leopold LB and Marchand MO (1968) On the Quantitative. Inventory of the Riverscape. Water Resources Research 4(4):709-717.

03

METHODOLOGY

03 METHODOLOGY

To assess the ecological status of the Godavari River, a reconnaissance was carried out from December 2021 to January 2022, to obtain an initial understanding of the river and its surrounding ecosystem by visiting approachable sites along the river, particularly the road heads. This survey helped in the identification of the river zones and the sampling points across the zones. Subsequently, two rapid assessments of the river were conducted to examine the current status of the river, the status of various taxa, the distribution of species of conservation significance vis-a-vis habitat conditions, water quality, and anthropogenic pressures that affect the integrity of the river ecosystem. The first intensive assessment was conducted in the pre-monsoon season during July to October 2022. This survey primarily focussed on the river bank vegetation, fish populations, herpetofauna, birds, and the otters. The second assessment was carried out in the post-monsoon from December 2022 to March 2023. The sampling was carried out in 29 selected stretches and the data generated were extrapolated to entire river stretches to identify biological hotspots for conservation prioritization.

3.1 Study Design

3.1.1 Zonation of the river

Before the survey, the identified total 1735 km study stretch of the Godavari River was categorized into three zones viz., (i) the Upper zone, (ii) the Middle zone, and (iii) the Lower zone based on geophysical conditions and physiographic characteristics (Figure 3.1, 3.2). The watercourse from the source to the Manjra confluence extending to 692 km represents the upper zone of the Godavari River. In this zone, the river passes through ridges and valleys interspersed with low hill ranges. The middle zone of the 319 km river stretches between the Manjra confluence and the Pranhita confluence. It is characterized by ridges and valleys interspersed with low hill ranges. The remaining 454 km stretch from the Pranhita River confluence to the mouth represents the lower zone. In this zone, the river flows through the flood plains (Table 3.1).

Figure 3.1 Map of flow and zones of the Godavari River

Parameter	Upper zone	Middle zone	Lower zone
Length	692 km	319 km	454 km
Stretch	Source to Manjra confluence	Manjra River confluence to Pranhita River confluence	Pranhita River confluence to mouth
Characteristics	Ridges and valleys interspersed with low hill ranges	Ridges and valleys interspersed with low hill ranges	Floodplain

(Pradhan, 2017)

Table 3.1 Characteristics of various zones of the Godavari River

Figure 3.2
View of Upper, Middle & Lower zones of the Godavari River

3.1.2 Sampling segments

A total of 29 sampling stretches were delineated using the GIS domain covering the upper, middle, and lower zones of the Godavari River. The selection of the sampling segments was based on the elevation profile of the river, level of habitat protection, exposure to urbanization and industrialization, and land use/land cover. Segments 1 to 14 represent the upper zone of the river, segments 15 to 19 in the middle zone, and segments 20 to 29 in the lower zone (Table 3.2). Of the total selected sampling segments, nine segments i.e., segments, 10, 11, 18, and 22 were not surveyed due to inaccessibility and bad weather.

Table 3.2: Sampling segments within Godavari river

Segment	Zone	State	Location	GPS Location		Elevation
				Start Point	End Point	(msl)
1			Beze, Nashik District	19 59 49.55 N, 73 35 40.70 E	20 00 13.71 N, 73 35 18.68 E	615
3			Chandgavhan, Ahilyanagar District	19 53 15.29 N, 74 25 46.53 E	19 52 24.43 N, 74 25 54.29 E	516
6			Gulaj Dam, Aurangabad District	19 22 43.34 N, 75 35 12.94 E	19 22 36.01 N, 75 37 06.17 E	410
8	Upper	Maharashtra	Dhalegao, Parbhani District	19 14 42.16 N, 76 20 58.46 E	19 12 46.93 N, 76 21 47.47 E	384
12			Rahati, Parbhani District	19 07 29.51 N, 77 10 05.55 E	19 06 36.79 N, 77 13 34.04 E	347
13			Khujda, Nanded District	19 00 46.07 N , 77 29 41.84 E	19 01 11.00 E 77 28 16.50 E	362
14			Kondalwadi, Nanded District	18 51 14.78 N, 77 47 59.10 E	18 52 02.47 N, 77 45 28.35 E	359
15			Aloor, Nizamabad District	18.830568 N, 77 29 41.84 E	18.824817 N, 77.890943 E	363
16	Middle	Telangana	Parpalle, Nizamabad District	18 58 08.48 N, 78 28 05.08 E	18 58 08.42 N, 78 25 45.50 E	395
17			Gudchiriyal, Nirmal District	19 03 33.09 N, 78 52 09.68 E	19 03 02.50 N, 78 53 01.20 E	221
19			Indaram, Adilabad, District	18 47 19.53 N, 79 31 08.28 E	18 46 56.92 N, 79 31 36.62 E	150
20		Telangana	Manddikunta, Karimnagar District	18 48 11.84 N, 79 57 18.03 E	18 46 35.00 N, 79 56 24.36 E	130
21			Neelampalle, Warangal District	18 39 37.19 N, 80 18 36.12 E	18 41 26.79 N, 80 18 00.15 E	108
23			Ramanakkapeta, Mulugu District	18 12 06.81 N, 80 36 51.46 E	18 11 22.92 N, 80 37 53.48 E	76
24			Chinnaravigundem, Mulugu District	17 56 24.88 N, 80 52 41.82 E	17 56 14.69 N, 80 53 31.93 E	70
25	Lower		Pinapally, Bhadrachalam District	17 38 43.74 N, 80 55 44.52 E	17 38 28.62 N, 80 53 35.17 E	60
26		Andhra Pradesh	Chinnapolipaka, Khammam District	17 36 00.76 N, 81 07 42.73 E	17 37 05.94 N, 81 06 08.61 E	50
27			Papikonda National Park, Raju District	17 26 20.10 N, 81 33 24.18 E	17 26 45.34 N, 81 32 29.29 E	40
28			Gandi Pochamma Ammavari Temple, Rajahmundry District	17 04 47.67 N, 81 44 57.09 E	17 04 25.21 N, 81 42 43.03 E	50
29			Vengeswarapuram, Yanam District	16 43 33.33 N, 81 58 03.84 E	16 43 31.59 N, 81 59 14.98 E	11

3.1.3 Sampling strategy

Within each 5 km long segment, three linear transects (1 km each) were laid. These transects were separated by a distance of one km to maintain the independence of the samples (Figure 3.3). On each of these transects, data on river habitat characteristics, vegetation, amphibians, reptiles, birds, and mammals, were systematically collected using standard data collection methods for each taxon group. This approach allowed for a comprehensive assessment of the environmental and biological factors within each segment of the Godavari River.

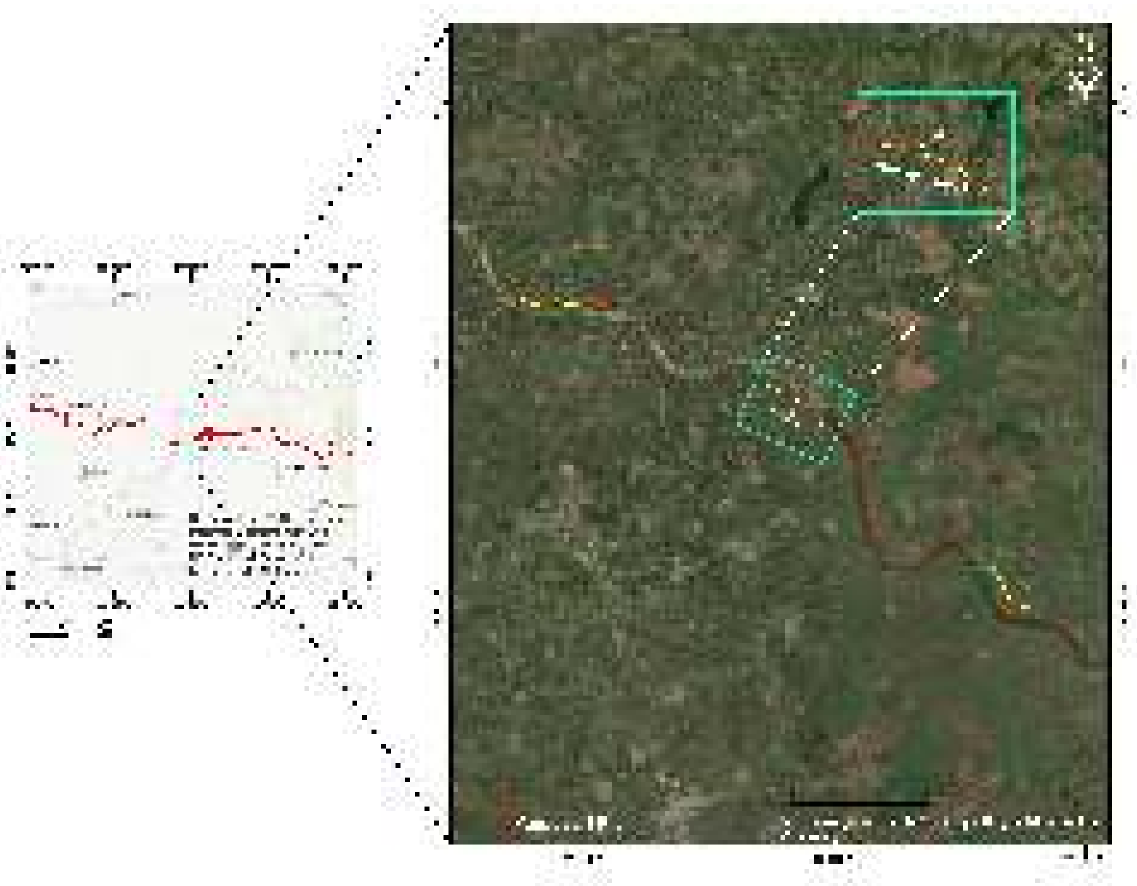


Figure 3.3 Sampling transects (1 km each) for biodiversity assessment in the Godavari River

3.2 Methods of data collection

On each transect, data on vegetation, fish, amphibians, reptiles, birds, and mammals were collected using various standard methods (Table 3.3). For the vegetation survey, the quadrate method was employed. Fish data was collected employing gill and cast net techniques. Data on amphibians and reptiles (snakes and lizards) was collected using time-frame Visual Encounter Methods. Data on terrestrial bird species was collected employing Mckinnon's Species Richness method and waterbirds by Total Count Methods. Direct and indirect evidence of mammals were recorded using the Line Transect method. Data on river morphology, physio-chemical properties of water, and bank characteristics was recorded using the standard equipment. Anthropogenic disturbances and pollution sources data were collected by counting the number of encounters along the transects (Table 3.3, Figure 3.4). We recorded both physical and chemical environmental variables at each sampling transect. Physical and chemical variables such as temperature, turbidity, stream velocity, conductivity, dissolved solids, pH, depth of river, and river width were recorded (Figure 3.5 & Figure 3.6). Additionally, the presence of various substrata such as rock, boulders, cobble, pebble and gravel, sand, silt, and clay were recorded at each sampling site. Around each transect, a one km buffer was created using the Buffer tool of ArcMap 10.3. Within each buffer,the amount of various land use/land cover classes was estimated.

Parameters	Group/taxa	Methods	Reference
River characteristics	Physico-chemical properties	Measurement using standard equipment	-
Bank characteristics	-	Measurement and visual	-
Vegetation	Trees	Quadrate Method (10 m radius)	Mishra (1968)
	shrubs	Quadrate Method (3x3 m)	Mishra (1968)
	Herbs	Quadrate Method (1x1 m)	Mishra (1968)
Fish	-	Cast Netting	Sarkar et al., (2012)
	-	Gill Netting	Sarkar et al., (2012)
Herpetofauna	Amphibians	Visual Encounter Method	Crump and Scott (1994)
	Reptiles	Visual Encounter Method	Crump and Scott (1994)
Birds	Terrestrial	McKinnon's Species Richness Method	Mackinnon and Phillips (1993)
	Waterbirds	Total Count Method	Koskimies and Vaisanen (1991)
Aquatic mammals	-	Line transects Method	Laake et al., (1979)
Hotspots	-	Maximum Entropy Modelling	Phillips et al., (2006)
Anthropogenic pressure	Human disturbance and pollution (Rapid urbanization and discharge of wastes)	Counting	

Table 3.3
Methods used during the ecological assessment of the Godavari River.

Figure 3.4
Data collection at sites in Godavari River

Figure 3.5
Water sample collection in the Godavari River

Figure 3.6
Recording of river characteristics in the Godavari River

3.3 Environmental factors influencing the abundance of various taxa

Canonical Correspondence Analysis (CCA) was used to identify the relationships of environmental variables with fish and bird assemblages. CCA is a multivariate method to elucidate the relationships between biological assemblages of species and their environment (Ter, 1986). The variables used to determine the relationship of various taxa with environmental variables are highlighted in Table 3.4.

Water	River	River substrate	Anthropogenic pressure	Landuse land change
PH	River width	Rock bed	Human	Built-up
Conductivity	River Depth	Boulder	Cattle	Agriculture
Water temperature	TDS	Cobbles	Fishing net	Green cover
Turbidity		Pebbles	Fishing boats	Degraded/scrub Forest
Dissolve oxygen		Gravel	Ferry boats	Grassland
Velocity of Water		Sand	Dumping of waste	Wasteland
		Silt	Sand mining	
		Clay	Water abstraction	

Table 3.4 Environmental variables used to assess the distribution of various taxa in the Godavari River

3.4 Habitat suitability and Stretches of Conservation Priority

The Ecological Niche Model (ENM) technique was employed to determine the suitable habitats for each species. We used the Maximum Entropy algorithm (MaxEnt) to model the habitat suitability of fish, water birds, and mammals (Phillips et al., 2006). MaxEnt is a maximum entropy-based machine learning program for predicting the probability distribution by using presence-only locations and a set of both continuous and discrete environmental variables (Elith et al., 2006; Franklin, 2010). Data collected from the field on water quality and anthropogenic pressure and remotely sensed layers on vegetation cover, and meteorology were used to assess the habitat suitability of various species.

Assessment of stretches of conservation priority in the Godavari River was determined using the habitat suitability for various taxa including fish, water birds, and mammals. All the habitat suitability models were merged to determine the stretches of conservation priority. Detailed methodology is provided in Chapter 11.

References

Crump M, Scott N, Heyer W, Donnelly M, McDiarmid R, Hayek L and Foster M (1994) Measuring and monitoring biological diversity: Standard methods for amphibians. Visual Encounter Surveys. 364

Elith J, Graham CH, Anderson RP, Dudík M, Ferrier S, Guisan A, Hijmans RJ, Huettmann F, Leathwick JR, Lehmann A and Li J (2006) Novel methods improve prediction of species' distributions from occurrence data. Ecography 29(2), 129-51.

Franklin J (2010) Mapping species distributions: spatial inference and prediction. Cambridge University Press, Cambridge.

Koskimies P and Väisänen RA (1991) Monitoring bird populations: a manual of methods applied in Finland. University of Helsinki, Zoological Museum.

IPCC (2003) Good practice guidance for land-use, land-use change and forestry.InPenman J, Gytarsky M, Hiraishi T, Krug T, Kruger D, Pipatti R, Buendia L, Miwa K, Ngara T, Tanabe K and Wagner FE (ed), Intergovernmental panel on climate change — national greenhouse gas inventories program. Institute for Global Environmental Strategies, Japan.

MacKinnon J and Phillips K (1993) A Field Guide to the Birds of Borneo, Sumatra, Java and Bali, the Greater Sunda Islands. Oxford University Press, Oxford.

Mishra R (1968) Ecology Work Book. Oxford and IBH Publishing Company, Calcutta, India.

Phillips SJ, Anderson RP and Schapire RE (2006) Maximum entropy modeling of species geographic distributions. Ecological Modeling25:190(3-4), 231-59.

Pradhan A (2017) Godavari Basin in Maharashtra: A Profile https://sandrp.in/2017/03/08/godavaribasin-in-maharashtra-a-profile/Accessed: 27th February 2019

Sarkar UK, Pathak AK, Sinha RK, Sivakumar K, Pandian AK, Pandey A, Dubey VK and Lakra WS (2012) Freshwater fish biodiversity in the River Ganga (India): changing pattern, threats, and conservation perspectives. Reviews in Fish Biology and Fisheries, 22(1), 251–272.

Ter BCJ (1986) Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. Ecology67, 167-1179.


04

RIVER CHARACTERISTICS

04

RIVER CHARACTERISTICS

Abstract

Anthropogenic activities such as the construction of dams, habitat degradation, introduction of invasive species, water abstraction, and changes in land use along the river course impact the natural characteristics of the river. We determined the river characteristics including the morphology of the Godavari River, its water characteristics, and the vegetation along its course to establish a baseline information that will serve as a reference point for evaluating the long-term impacts of anthropogenic activities on the river. Morphological analysis reveals that Godavari River flows from an elevation of 615 meters,and descends to 11 meters above sea level with slopes fluctuating between 0 to 67 degrees, depth ranging between 0.2 to 13.93 meters and width between 14.58 to 3844 meters. Physicochemical analysis indicated that the flow of the water ranges between 0 to 1.80 m/s, conductivity between 0 to 1866.73 µS/cm, dissolved oxygen between 2.26 to 14.19 mg/l, total dissolved solids between 0 to 942.5 ppm, turbidity between 0.14 to 68.33, salinity between 80.14 to 22167.6 mg/l, pH ranges between 7.7 to 9.8. Bank of the Godavari River in the upper zone is sandy, clay, and loam, with rocky and muddy dominance in the upper zone, sandy and rocky in the middle, and sandy in the lower. Normalized Difference Vegetation Index (NDVI) around (500m buffer) ranges between -0.55 to 0.68. This comprehensive baseline information could serve as a valuable foundation for monitoring and evaluating the long-term repercussions of anthropogenic activities on the Godavari River, for informed decision-making and sustainable management practices.

4.1 Introduction

The Godavari River, also known as the Dakshina Ganga or Vridha Ganga, holds the distinction of being the largest river in peninsular India. Its basin encompasses nearly 9.5% of the country's total geographical area. Originating from Trimbakeshwar in the Western Ghats in the Nashik district of Maharashtra, the river gracefully traverses the expanse from the Western to the Eastern Ghats, cutting across the Deccan Plateau. The Godavari River meander through the states of Maharashtra, Chhattisgarh, Telangana, and Andhra Pradesh before culminating its journey in the Bay of Bengal. The river delineates inter-state boundaries between Telangana and Maharashtra, as well as Telangana and Chhattisgarh.

However, the Godavari basin has been subjected to land use changes over the years, such as an increase in the urban and built-up areas, and changes in the water, forests, and agricultural areas. In the Godavari basin, during 1984-2010, the water areas decreased by 0.41% till 2010, and grassland/cropland witnessed a reduction of 9.57% till 2010. The Evergreen Broadleaf Forest and the closed Shrubland witnessed a decrease by 0.25% and 3.93%, respectively. In 2010, the areas under the urban and built-up areas were observed to increase by 0.87%, while the area under the woodland was augmented by 9.19%. (Hengade and Eldho, 2019). Additionally, numerous significant dams and reservoirs, such as the Pochampad Dam, Jayakwadi Dam, and Srisailam Dam, have been constructed on the river, ensuring a steady supply of water for agricultural, drinking, and industrial needs in the region (Central Water Commission, 2014).

Anthropogenic activities are the main cause of river morphology changes (Kong et al., 2020; Ibitoye, 2021). Studies investigating the impact of LULC changes on river morphology are limited and only a few research have been conducted in Portugal (Fernandes et al., 2020), Iran (Yousefi et al., 2016) and Nigeria (Ibitoye, 2021). In India, river morphology is assessed for the Jhelum River due to an extreme flood event (Himayoun and Roshni, 2020). Nath and Ghosh (2022) highlighted the morphological changes in the Barak River to quantify the changes in the spatial and temporal variation of the sinuosity index and their effect on morphological characteristics. Nath and Ghosh (2022) further investigated morphological changes in the Barak River from 1990 to 2020. However, studies on Godavari River characteristics are lacking hitherto.

We assessed the morphology of the Godavari River, its water characteristics, and the vegetation along its course. Such information is essential for developing a comprehensive understanding of the river's natural state, any deviations resulting from anthropogenic activities, and long-term conservation to maintain the ecological balance of the Godavari River.

4.2 Methodology

To characterize the Godavari River; data on the physical parameters of water, river morphology, bank characteristics at the starting and ending points of each transect, and human disturbance and pollution sources along the transects were recorded during surveys. Physical parameters of water include temperature, velocity, and turbidity. River morphology characteristics include channel type (straight, meandering, braided, and anastomosing), width, and depth (Figure 4.1). Channel substratum was categorized as either rocky or muddy. Bank characteristics include slope, substratum (sandy, muddy, rocky, boulders, cobbles, pebbles, clay rocky intermixed and amount of bank vegetation (exposed/partial/fully covered). Elevation was recorded using a hand-held Global Positioning System (GARMIN 2.3), channel width with the help of a range finder (LRF900), velocity of the watercourse using a standard flow meter (Geopacks: model), river depth using a portable depth finder (Depthtrax 1H: model).

Spatial interpolation technique viz., Kriging was used to estimate the level of anthropogenic pressure, and water quality parameters in the non-sampled area. Spatial Kriging (without nugget effects) generated landscape-level maps of hotspots for anthropogenic pressure. We fit linear models to the observed data based on AIC in Kriging Interpolator 3.2 for Spatial Analyst in ArcView to generate maps.

Figure 4.1
Data collection on river characteristics in Godavari River

4.3 River Characteristics

4.3.1 River morphology

The morphological analysis revealed that the Godavari River originates from an elevation of 615m, and descends to sea level, reaching an elevation of 11m. The river slope gradient fluctuates between 0 to 67° throughout the Godavari River. The depth of the Godavari River exhibited variations from 0.2 m to 13.93 m, with an average depth of 6.98 m (Figure 4.2 to 4.5). The deepest area of the Godavari River was observed in Papikonda National Park, Andhra Pradesh. The width of the Godavari River ranged between 14.58 m and 3771.68 m. The average width of the Godavari River was 1893.13 m. Notably, the lower zone exhibited the widest expanse. Table 4.1 highlights the morphological characteristics of the Godavari River.

4.3.2 Water characteristics

Regarding the physicochemical properties of the Godavari River, the river's flow velocity ranged between 0 to 1.80 m/s. The electrical conductivity of water varied between 0.0 and 1866.73 μS/cm, with the highest levels observed in the upper zone. The dissolved oxygen ranged between 2.26 to 14.19 mg/l, averaging 8.225 mg/l. The TDS concentration ranged between 0 to 942.5 ppm, averaging 471.25 ppm. The highest TDS level was observed in the Upper zone. The turbidity ranged between 0.14 to 68.33%, averaging 34.235%. The maximum values of flow velocity, electrical conductivity, and TDS were observed in the upper zone. The ambient temperature ranged between 22.30 to 33.20 °C with an average temperature of 27.75 °C. The pH concentration fluctuated between 7.7 to 9.8, with the highest values recorded in the lower zone and some parts of the middle and upper zone. The average pH of the Godavari River water was found to be 8.75. The salinity ranged between 80.14 to 22167.6mg/l, averaging 11123.87 mg/l and rainfall varies between 491 to 2577 mm, averaging 1534 mm (Figure 4.6 to 4.14; Table 4.1).

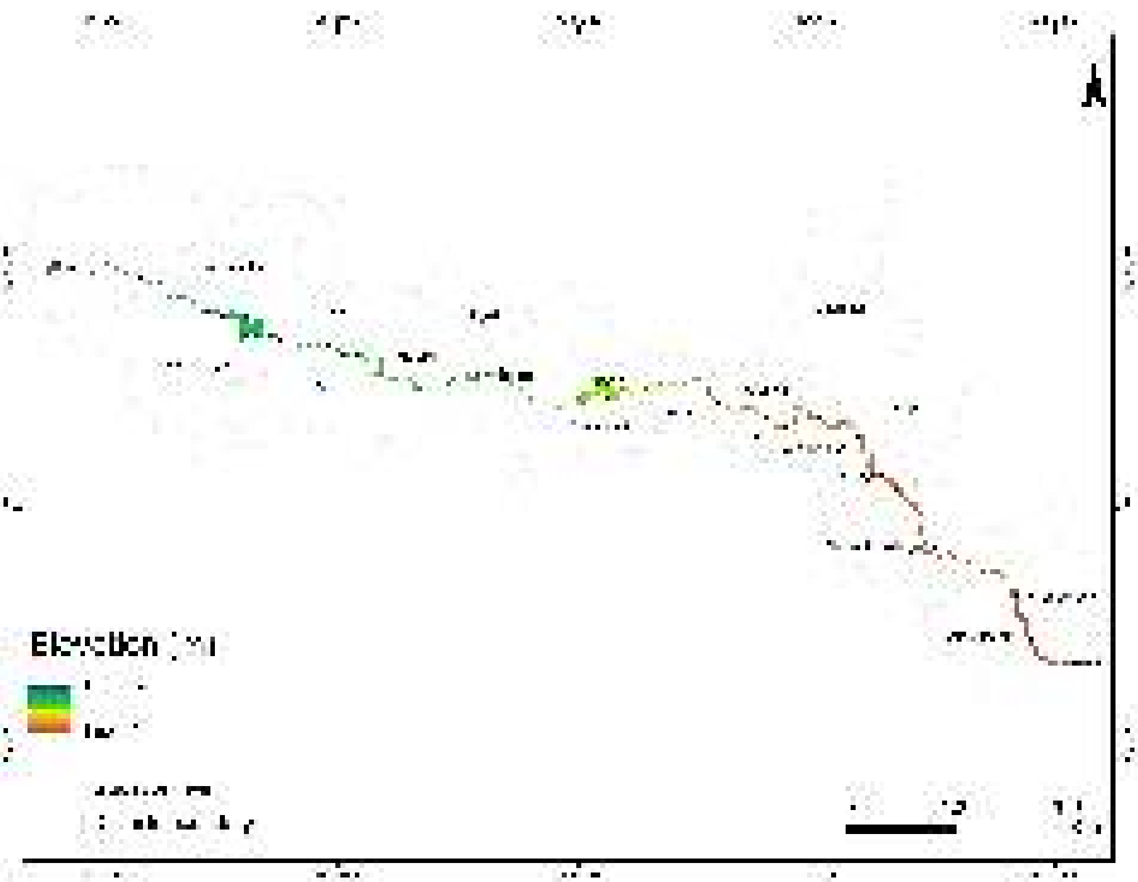
4.3.3 Bank characteristics

The soil on the bank was represented by three different types: sandy, clay, and loamwith rocky and muddy dominating the upper zone. The middle zone soil is represented by sandy and rocky soil and the lower zone by sandy soil (Figure 4.15 to 4.17; Table 4.1). The NDVI value of at the bank ranges between -0.55 to 0.68.

Table 4.1
Characteristics of the Godavari River

Characteristics	Parameter	Mean	Minimum	Maximum
River morphology	Elevation	453.5	0	907
	Slope	33.44	0	66.88
	River depth	6.975	0.02	13.93
	River width	1893.13	14.58	3771.68
Water characteristics	Electrical conductivity (mS/cm)	933.365	0.0	1866.73
	Dissolved oxygen (DO) (mg/l)	8.225	2.26	14.19
	Flow velocity (m/s)	0.9	0	1.80
	pH	8.75	7.7	9.8
	Salinity (mg/l)	11123.87	80.14	22167.6
	Total dissolved solids (TDS) (mg/l)	471.25	0.0	942.5
	Turbidity (NTU)	34.24	0.14	68.33
	Water temperature (ºC)	27.75	22.30	33.20
Meteorology	Rainfall (mm)	1534	491	2577
Bank Characteristics	NDVI	0.065	-0.55	0.68

Figure 4.2
Elevation profile of the Godavari River



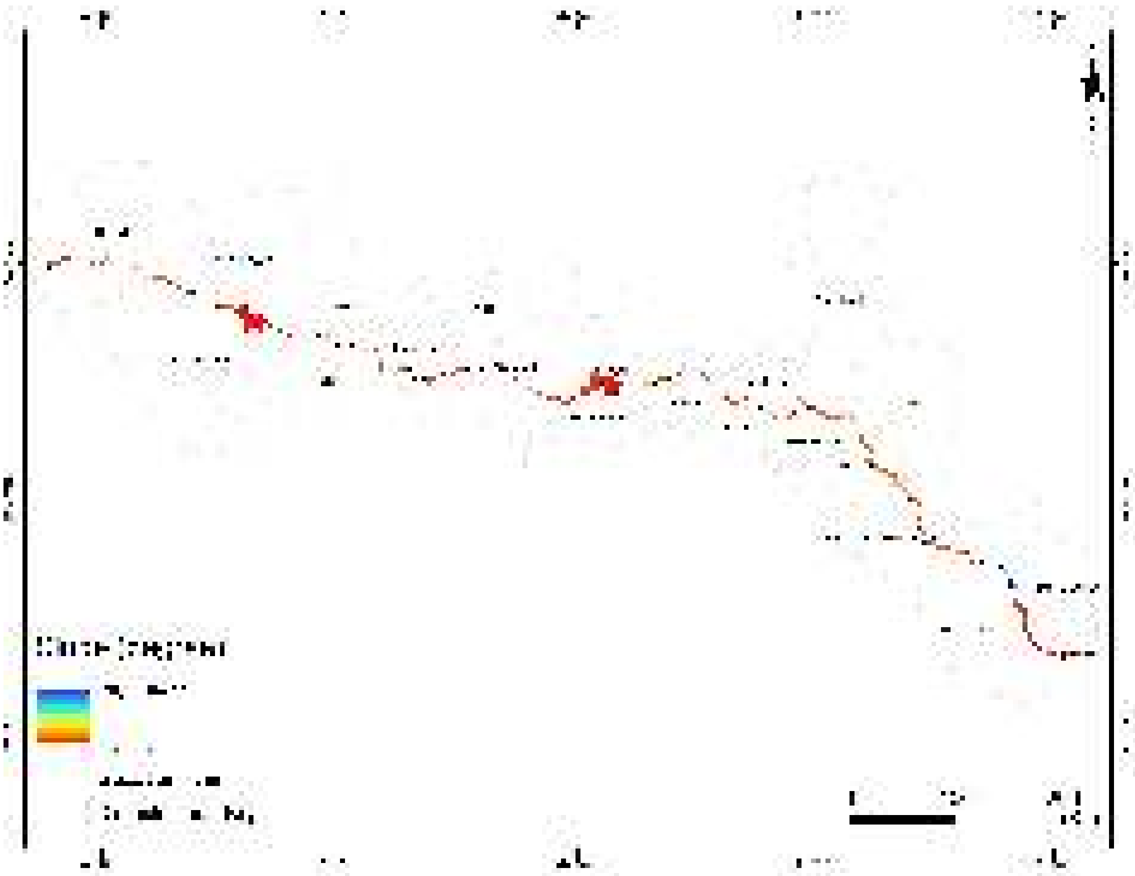


Figure 4.3 Slope gradients of the Godavari River

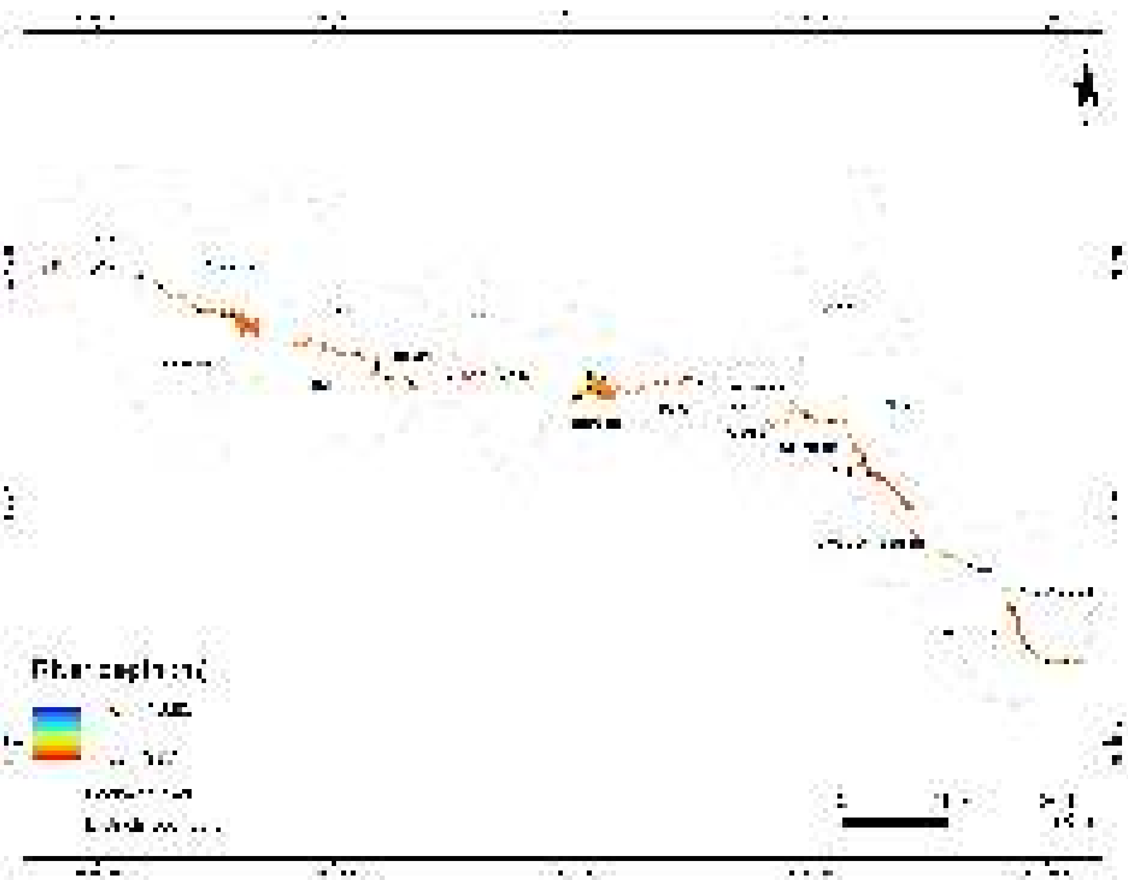


Figure 4.4 Depth profile of the Godavari River

Figure 4.5
Width profile of the Godavari River

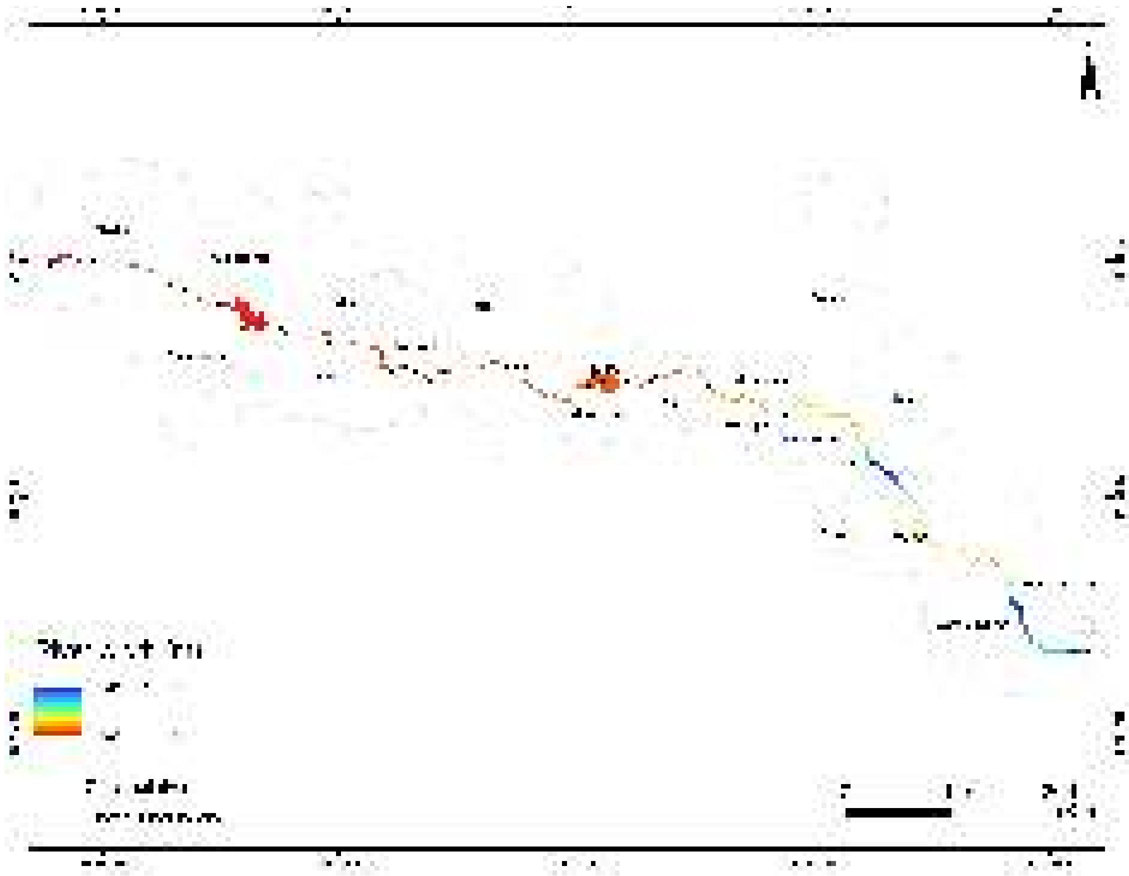
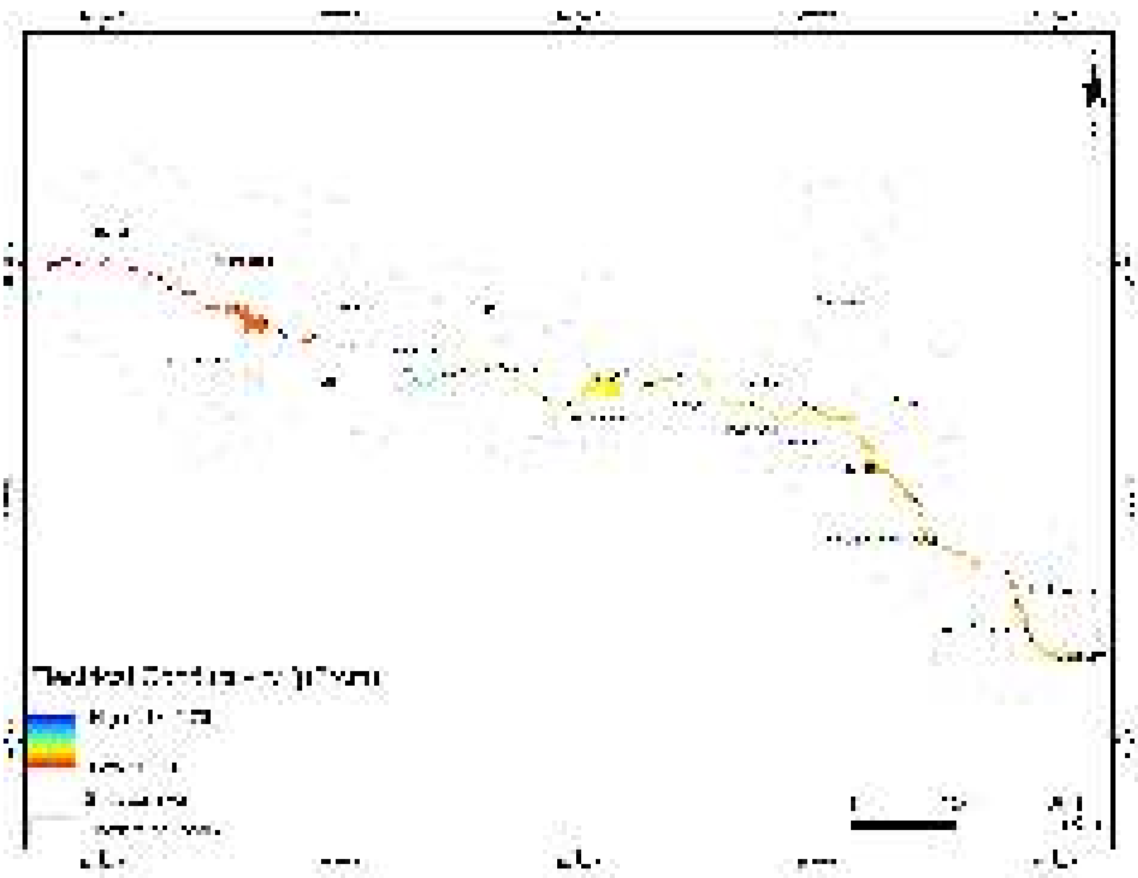


Figure 4.6
Spatial distribution of electric conductivity in Godavari River



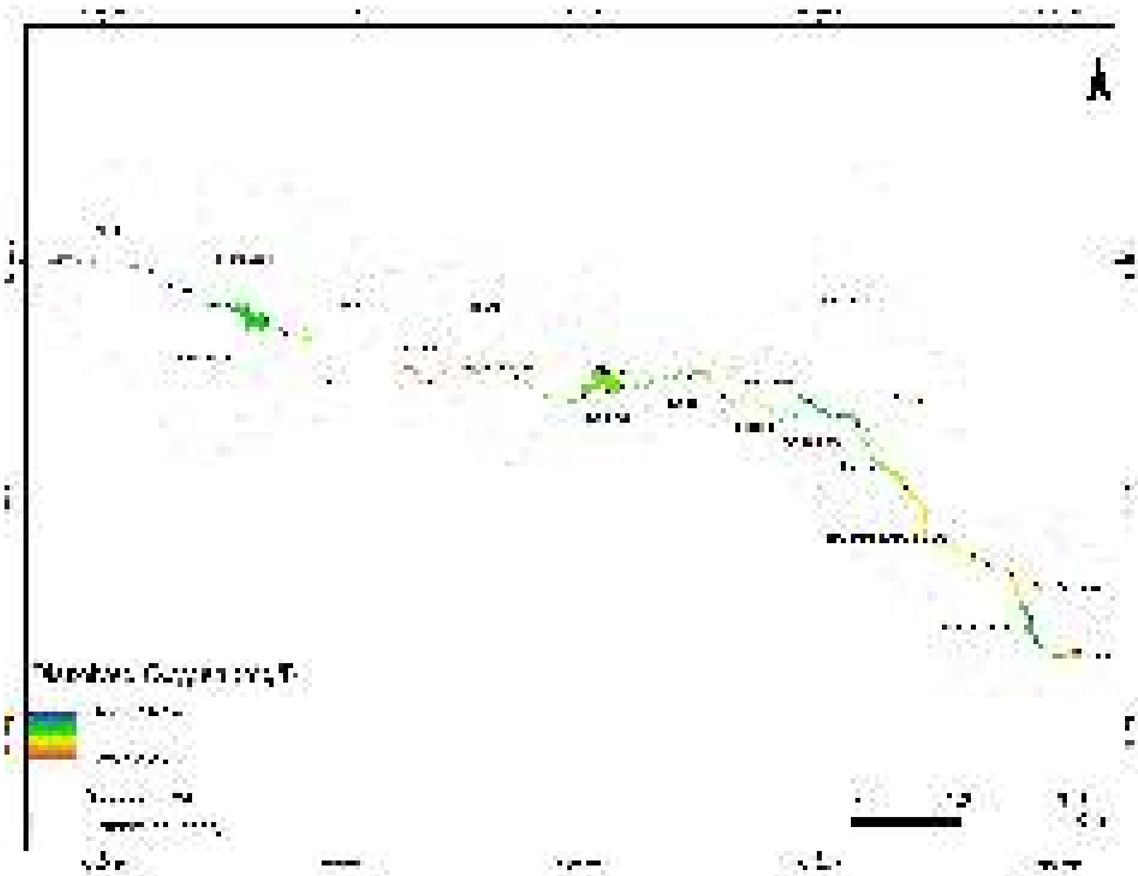


Figure 4.7 Spatial distribution of dissolved oxygen in Godavari River

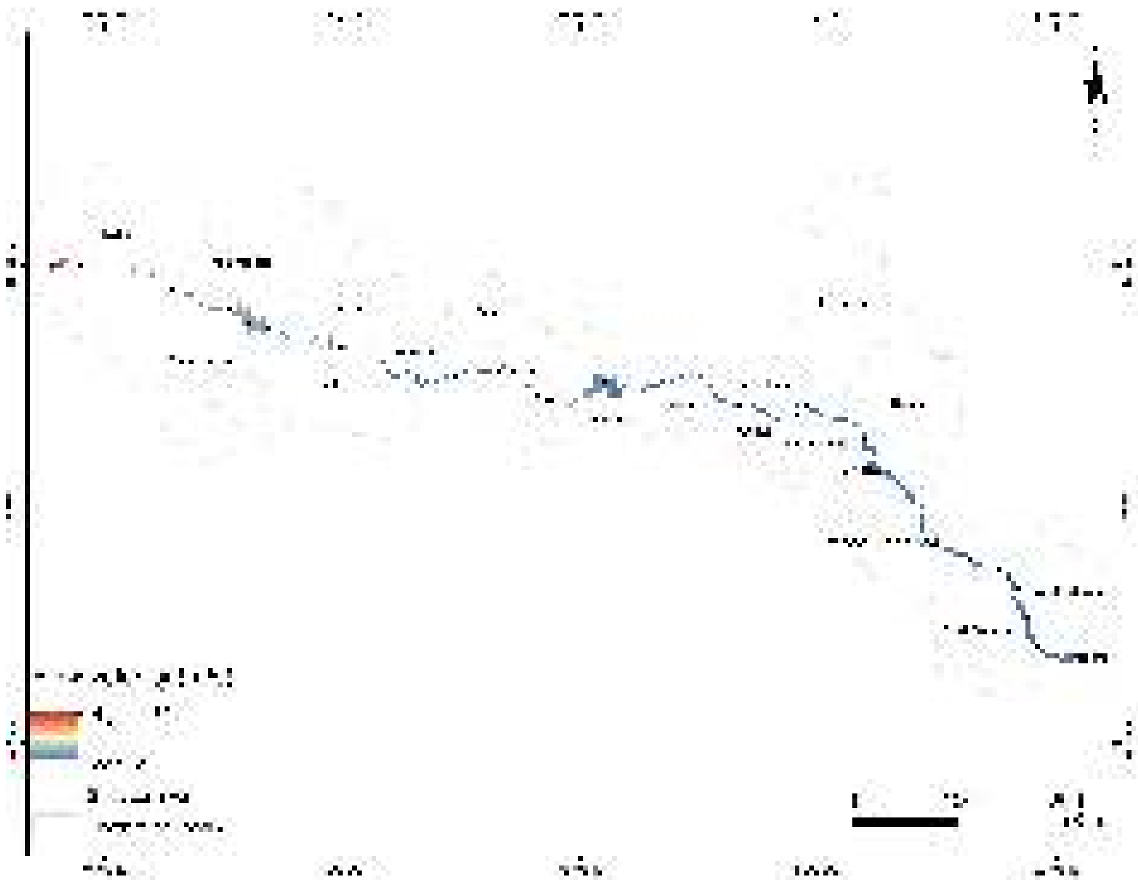


Figure 4.8 Spatial distribution of flow velocity in Godavari River

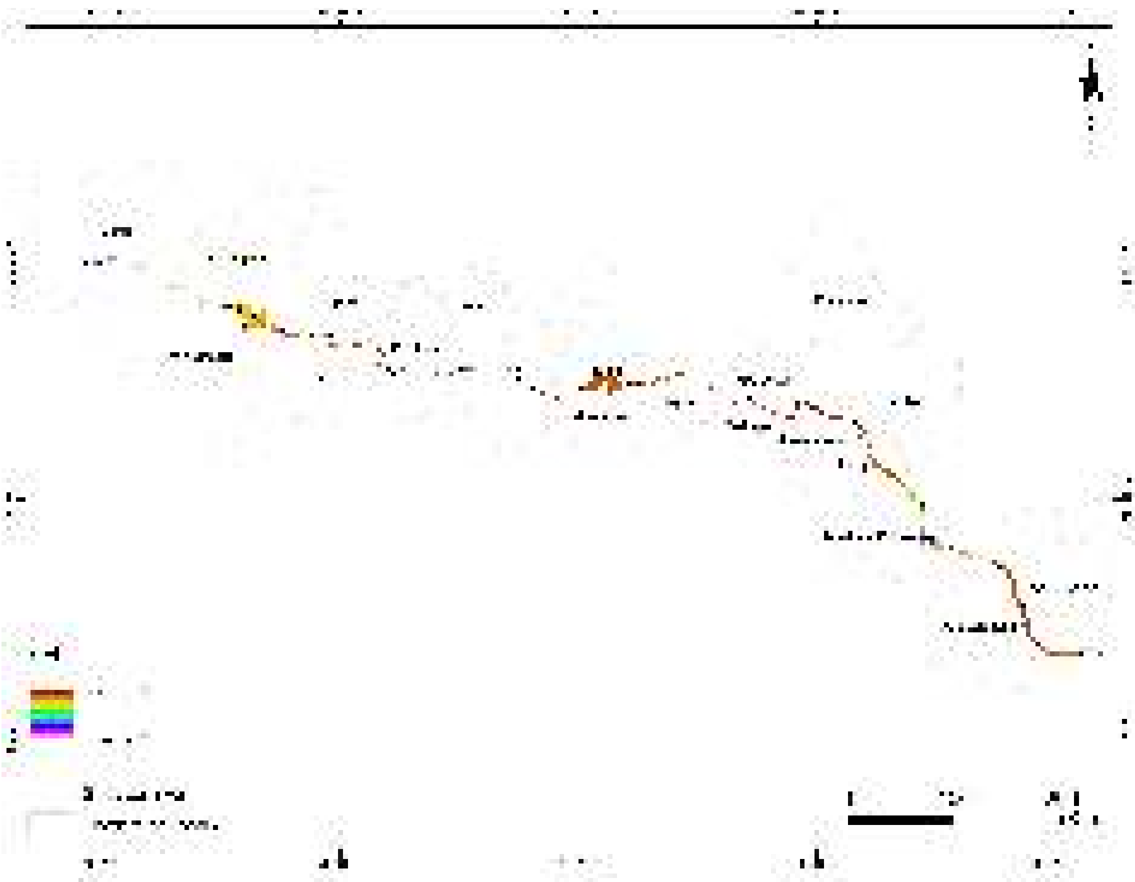


Figure 4.9 Spatial distribution of pH in Godavari River

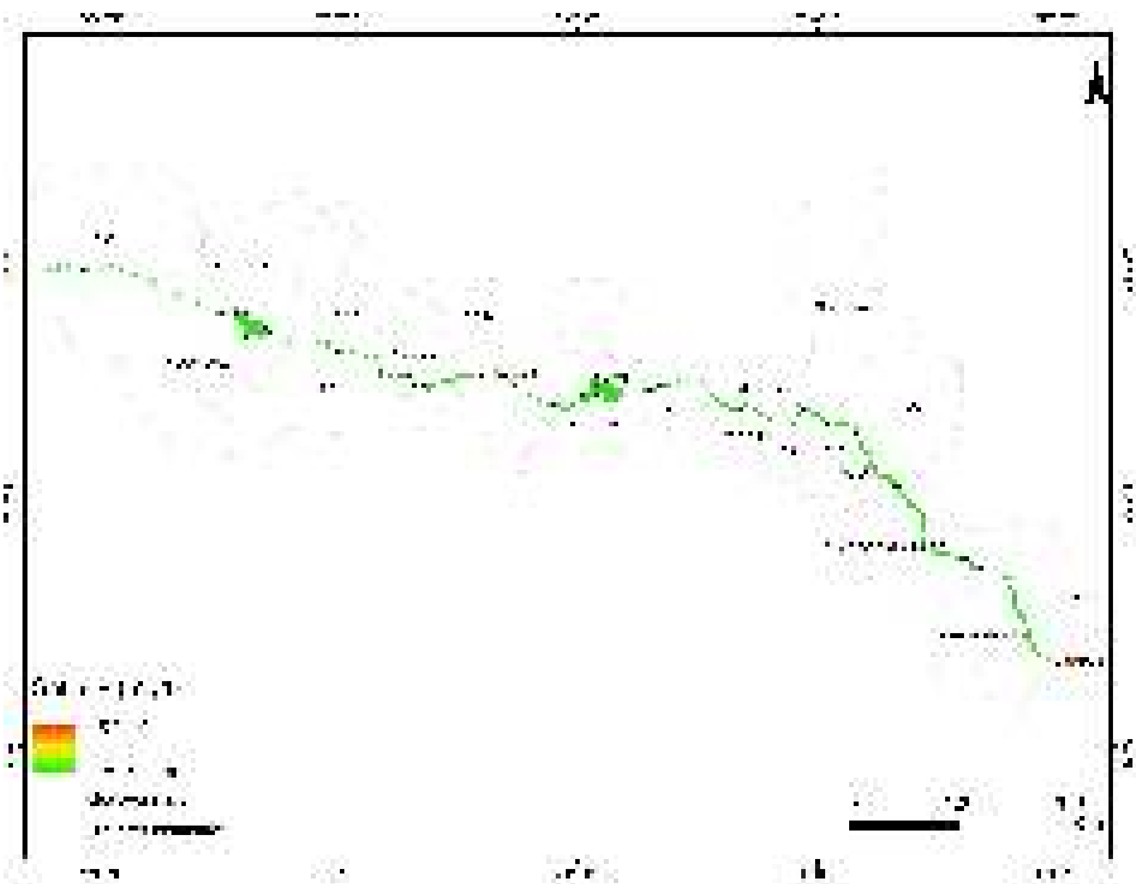


Figure 4.10 Spatial distribution of salinity in Godavari River

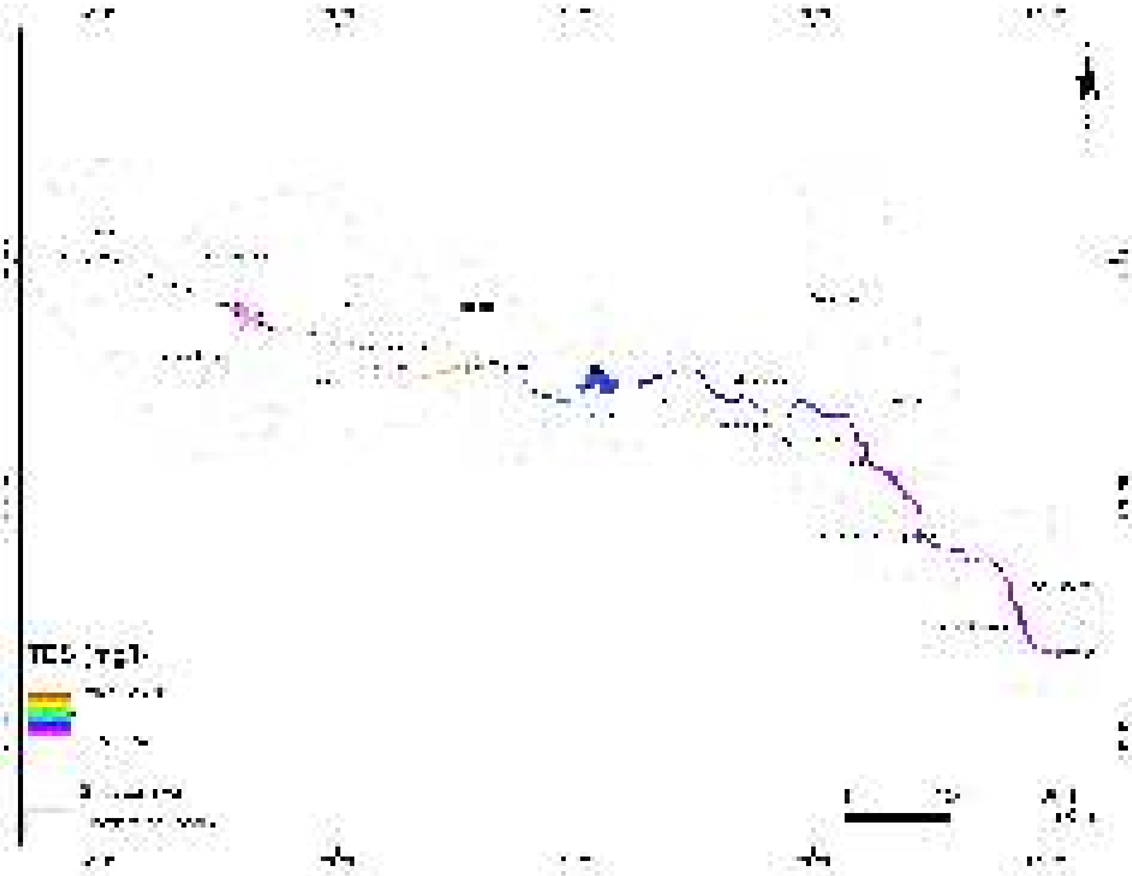


Figure 4.11 Spatial distribution of TDS in Godavari River

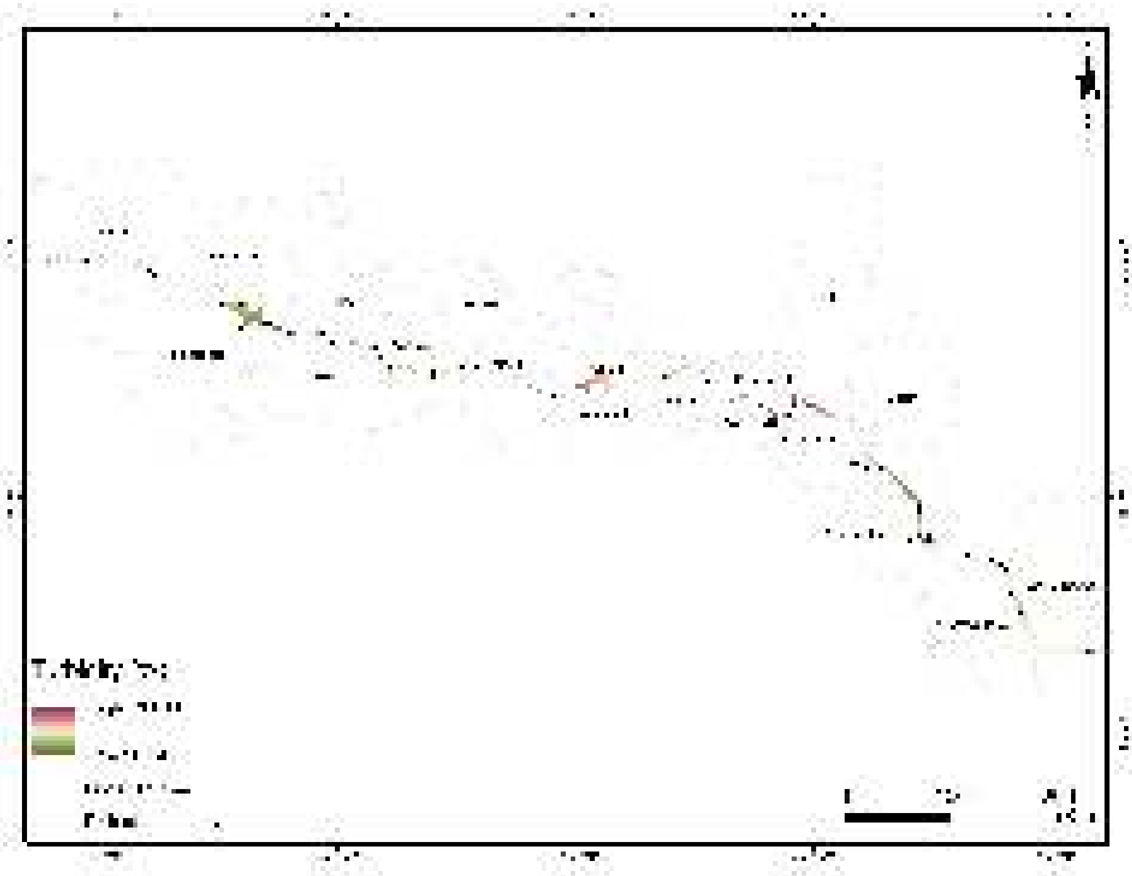


Figure 4.12 Spatial distribution of turbidity in Godavari River

Figure 4.13 Spatial distribution of water temperature in Godavari River

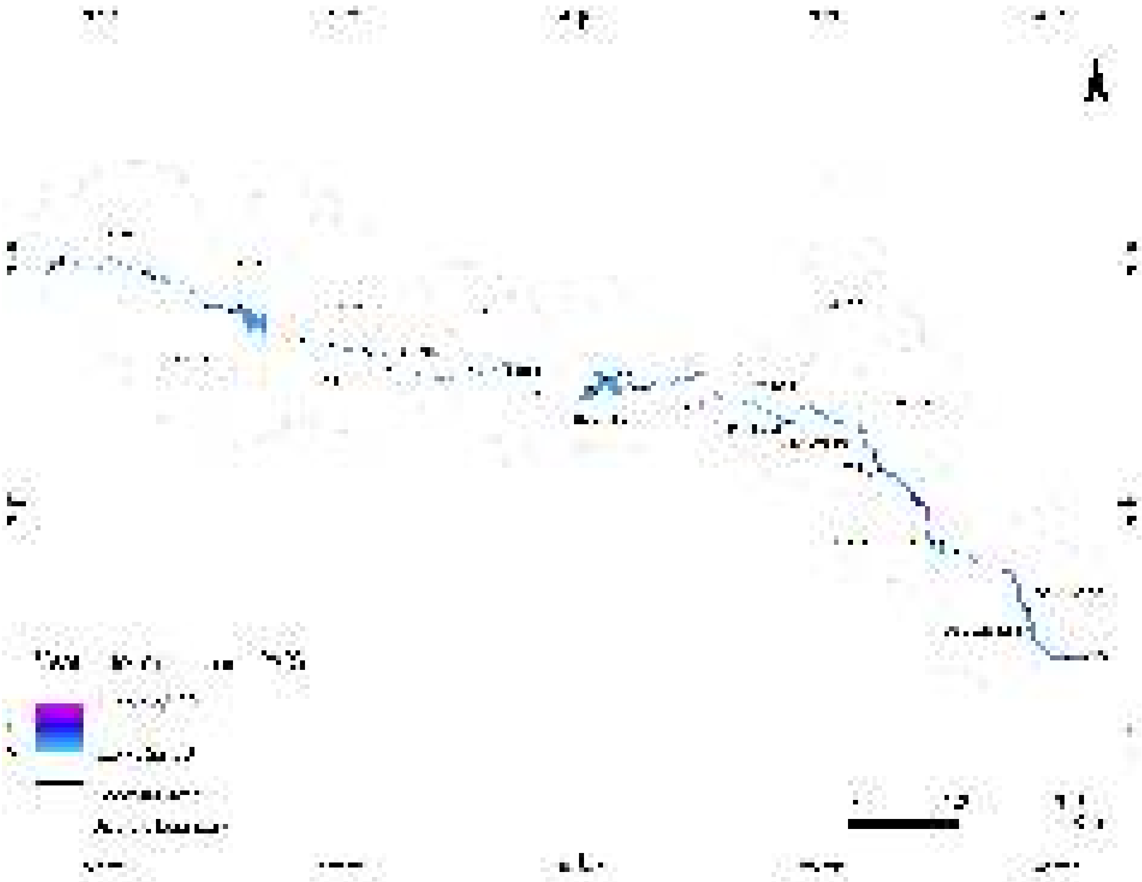
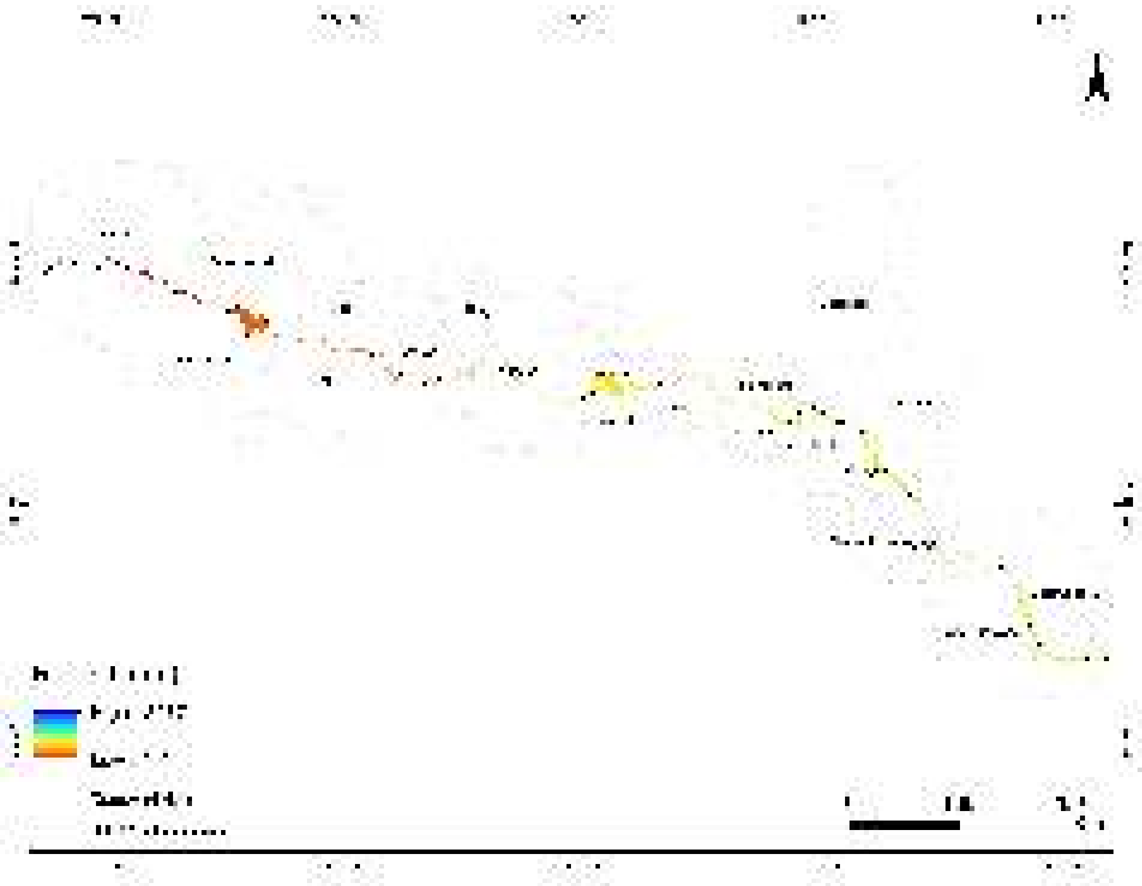


Figure 4.14 Spatial distribution of rainfall in the Godavari River



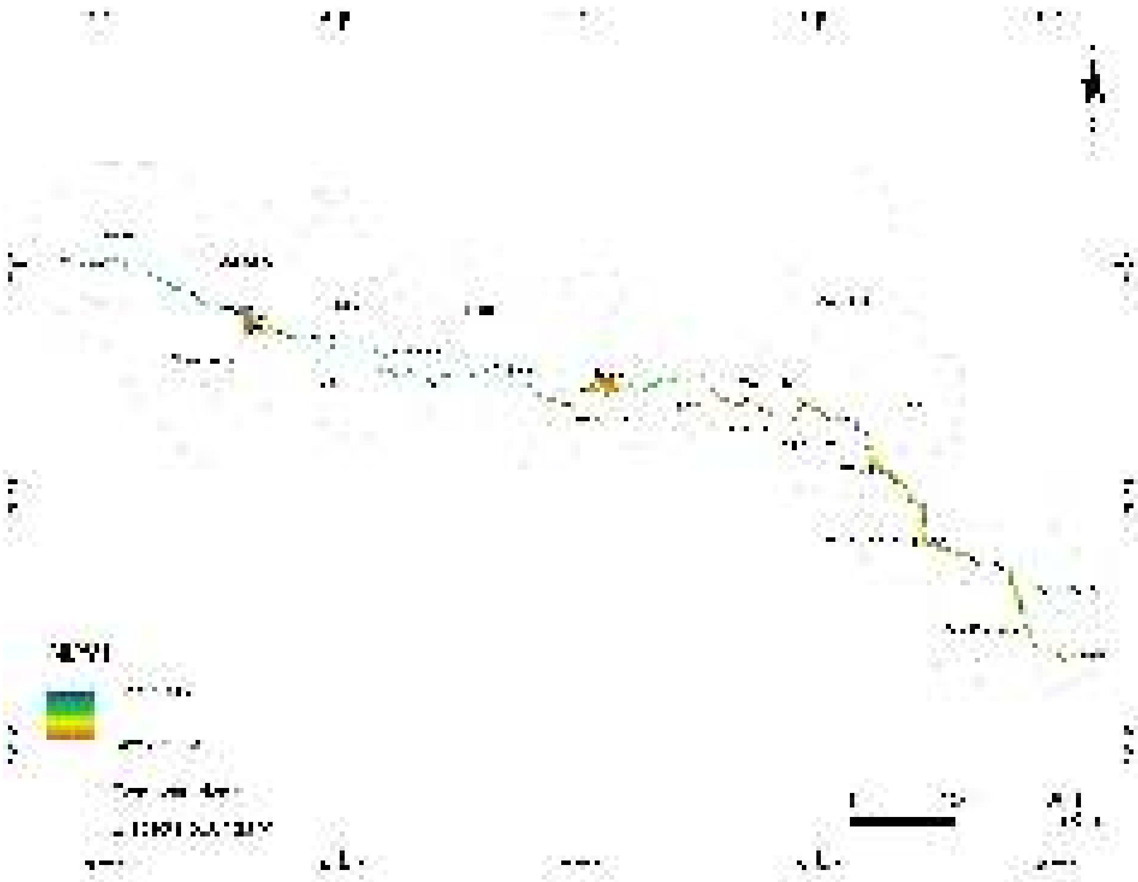


Figure 4.15
Spatial distribution of NDVI in Godavari River

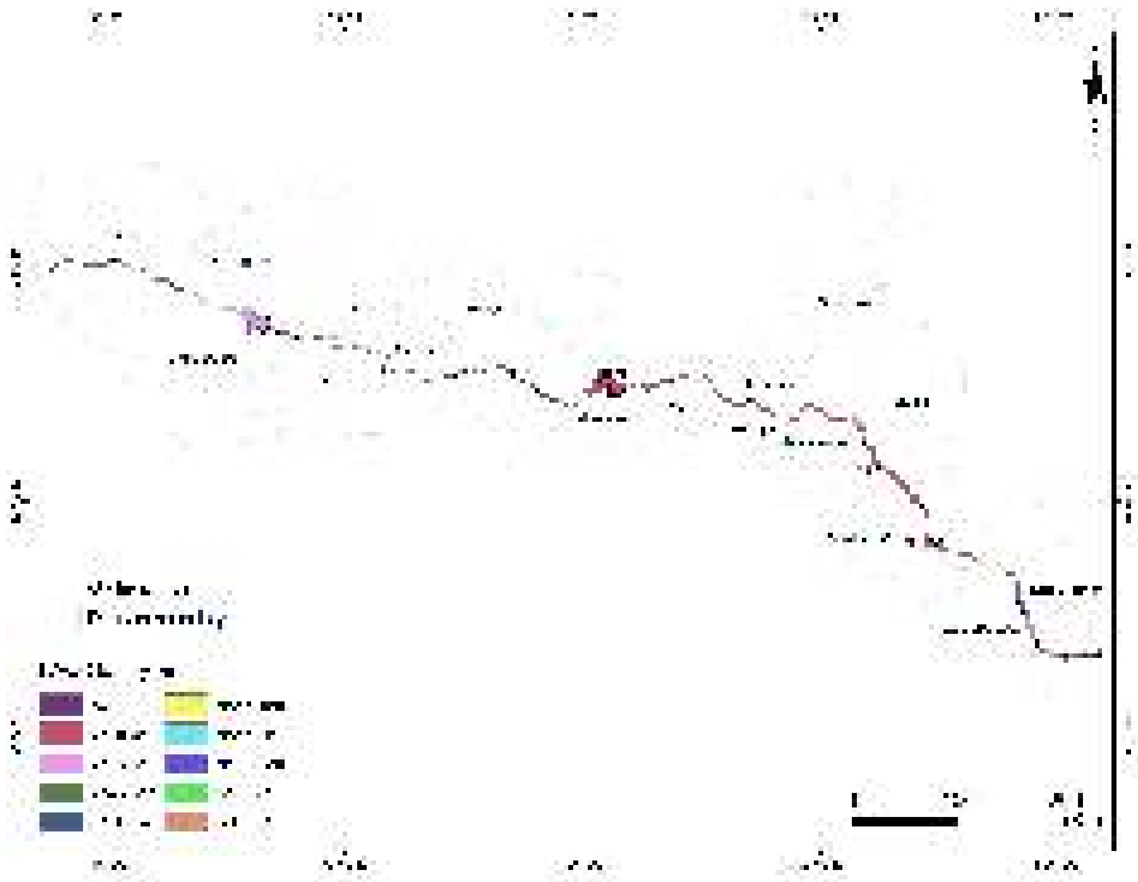
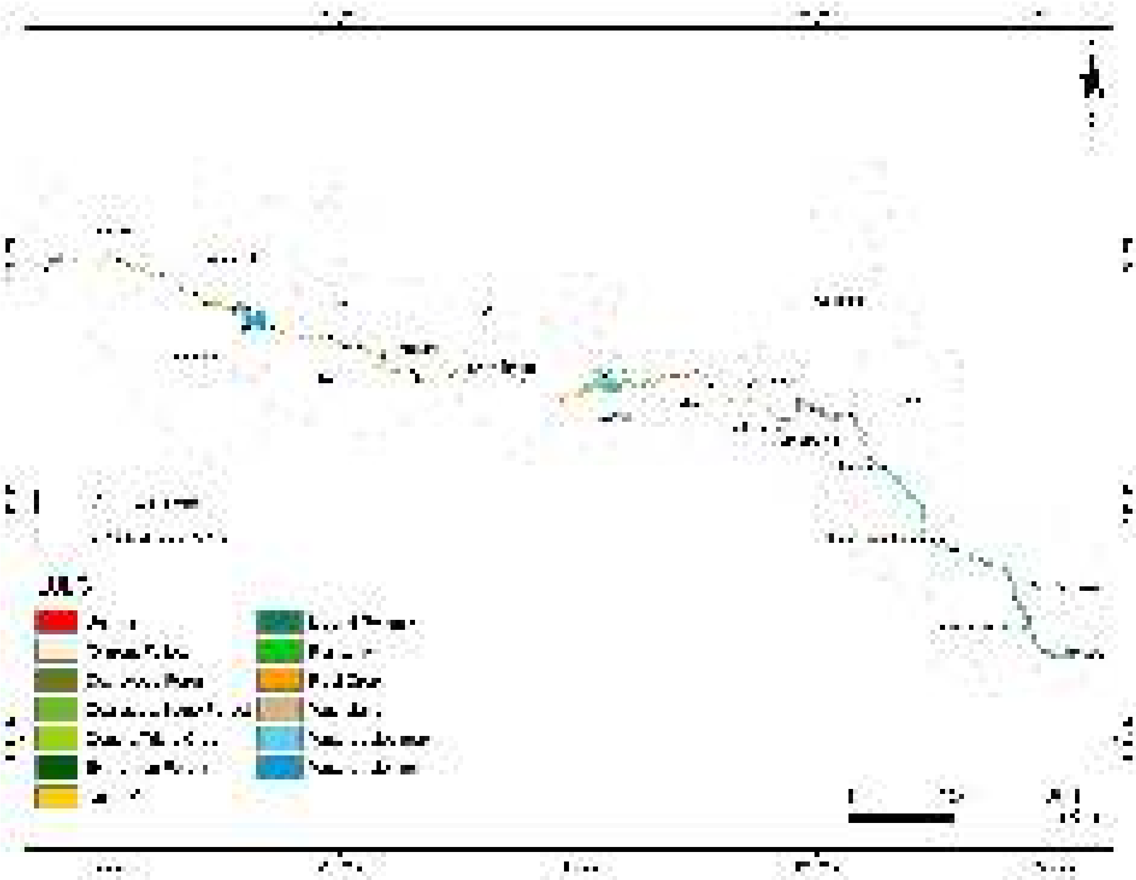


Figure 4.16
Soil type of the Godavari River

Figure 4.17
Land use and land cover (LULC) of the Godavari River



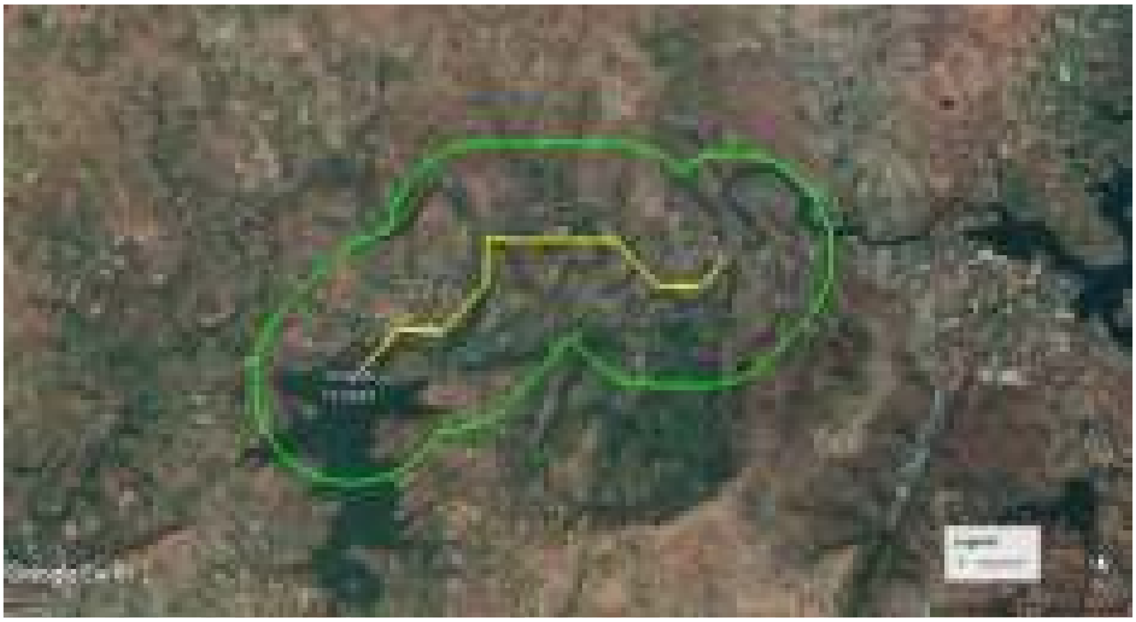
4.4 Description of the Sampling Segments

A total of 29 sampling segments were delineated using the GIS covering the upper, middle, and lower zones of the Godavari River (Table 4.2). The selection of the sampling stretches was based on the elevation profile of the river, level of habitat protection, exposure to urbanization and industrialization, and land use/land cover. Segments 1 to 14 represent the upper zone of the river, segments 15 to 19 in the middle zone, and segments 20 to 29 in the lower zone. Of the total selected sampling segments, nine segments i.e., segment numbers 2, 4, 5, 7, 9, 10, 11, 18, and 22 were not surveyed due to inaccessibility and bad weather.

4.4.1 Sampling Segment 1

Segment 1 is located downstream of Beze village in the Nashik district, Maharashtra (N 19° 59' 49.55", E 73° 35' 40.70" to N 20° 00' 13.71", E 73° 35' 18.68") at an elevation of 615 m above mean sea level. The nearest human settlement is at a distance of 76 m from the riverbank. The river in this segment is a single narrow channel at the start, and meander at the end, with a minimum and maximum width of 32 m and 80 m. This segment at the beginning is characterized by a rocky substratum and muddy toward the end (Figure 4.18). The water is clear (0% turbidity), with a velocity between 0.3 m/s and 2.4 m/s. The channel depth ranges between 0.1 m to 3.8 m. The riverbank which is a steep slope at the beginning with an exposed rocky substratum devoid of trees, gentle slope at the end where the riverbank is partially covered by herbs i.e *Alternanthera sessilis, Parthenium hysterophorus*, and *Hygrophila auriculate* and grasses i.e. *Themeda triandra, Cynodon dactylon*, and *Chloris virgata*. Human activity in the segment is mainly in the form of small-scale fishing using cast nets.

Figure 4.18 Segment 1- Rajewadi and Chakor village, Nashik district, Maharashtra



4.4.2 Sampling Segment 3

This segment is located near the Chandgavhan village in the Ahilyanagar district, Maharashtra (N 19° 53' 15.29", E 74° 25' 46.53" to N 19° 52' 24.43", E 74° 25' 54.29") at an elevation of 516 m and 120 m distance from human settlement. The river in this segment is a wide-single straight channel at the start and a wide meander at the end. The channel width ranges between 170 m and 259 m. The riverbank substrate is dominantly muddy throughout the survey segment. The presence of a small check dam downstream of this segment, dictates the physical nature of the water channel in this segment (Figure 4.19). The water is 10% turbid towards the beginning and 40% towards the end. The river has a restricted flow with a velocity ranging between 0.3 m/s and 0.9 m/s. The average depth of the river channel is 3.54 m, ranging from 0.1 m to 7.2 m. Both the riverbanks are either completely or partially covered with vegetation. The dominant tree species was *Prosopis juliflora*. Riverbank agriculture is significant in this segment with associated activities such as river water extraction using temporary and submersible water pumps. Fishing using gill nets was also observed in this segment.

Figure 4.19
Segment 3- Chandgavan village, Ahilyanagar district, Maharashtra

4.4.3 Sampling Segment 6

This segment is located downstream of the Gulaj Dam near Hiradpur village in Aurangabad district, (N 19° 22' 43.34", E 75° 35' 12.94" to N 19° 22' 36.01", E 75° 37' 06.17") at an elevation of 410 m, and 100 m from the nearest human settlement. The river in this segment is a wide single straight channel at the start, a narrow meander at the middle, and a narrow single straight channel at the end with a minimum and maximum width of 9 m and 155 m. The river channel here is heavily modified due to the Gulaj dam. During the survey, all the gates of the dam were closed resulting in a lean flow downstream of the dam (Figure 4.20). The river bed was completely exposed showing a rocky substratum with small boulders. Further downstream, the bank substratum was muddy with a mixture of sand and gravel closer to the shore. The river depth in this segment ranged from 0.1 m to 1.5 m. The most dominant vegetation was *Prosopis juliflora*, indicative of a highly disturbed habitat. Both riverbanks are surrounded by agriculture and associated water-harvesting activities. Sand mining was being practiced on a small scale, where two individuals were transporting gravel and sand on motorbikes from the riverbank. Approximately 3 km downstream, near Apegao, there is a temple and a pilgrimage site on either riverbank. This location is frequented by a large number of devotees and is a source of water pollution arising from religious activities such as bathing in the river and immersing in religious offerings.

Figure 4.20 Segment 6-Godavari River, downstream of the Gulaj Dam

4.4.4 Sampling Segment 8

This segment is located downstream of Dhalegao village in Parbhani district in Maharashtra (N 19° 14' 42.16", E 76° 20' 58.46" to N 19° 12' 46.93", E 76° 21' 47.47") at an elevation of 384 m and 800 m from the nearest human settlement. The river throughout this segment is a wide meander channel. The channel width is between 99 m and 348 m. The substratum is a mixture of sand and mud at the beginning with more prevalence of sand at the end (Figure 4.21). The turbidity of the water ranges between 10% and 30% at the end. The presence of a barrage downstream of the segment has restricted the natural flow of the river. During the survey, since all the barrage gates were closed, river flow was nearly stagnant. The average depth in this segment is 3.07 m, ranging from 0.6 m to 6.9 m. The riverbanks in this segment are gently sloped with a partial cover of vegetation. The dominant species of vegetation was *Prosopis juliflora*. Human activity in this segment is largely in the form of agriculture, cattle grazing, and garbage dumping in some spots.

Figure 4.21 Segment 8- Dhalegao, Beed district, Maharashtra

4.4.5 Sampling Segment 12

This segment is located near Rahati village in the Parbhani district, Maharashtra (N 19° 07' 29.51", E 77° 10' 05.55" to N 19° 06' 36.79", E 77° 13' 34.04") at an elevation of 347 m, and a distance 600 m from the nearest human settlement. The river channel is wide with partial meanders. The channel has a minimum and maximum width of 228 m and 348 m. The riverbank substratum is predominantly a mixture of mud and clay. This segment lies approximately 8 km upstream of the Vishnupuri dam at Nanded (Figure 4.22). The physical nature of the river is governed by the functioning of the dam, and as a result, there was no visible flow in the river and the water turbidity ranged between 10% and 40%. The surrounding areas showed signs of dam backwater inundation and pooling effects in the river. The riverbanks were predominantly muddy substratum with deposits of sand and gravel interspersed. The average depth in this segment is 2.48 m, ranging from 0.3 m to 4.2 m. Vegetation is a mix of grasses and shrubs with a few trees. The most dominant species is *Prosopis juliflora*. Sand mining was observed in this segment, where sand was being mined from the left bank of the river and transported to the opposite bank. Excavated sand was dumped on the opposite bank and further transported via tractors and trolleys. Agriculture was the most common anthropogenic land use activity in this segment.

Figure 4.22 Segment 12- Rahati, Parbhani district, Maharashtra

4.4.6 Sampling Segment 13

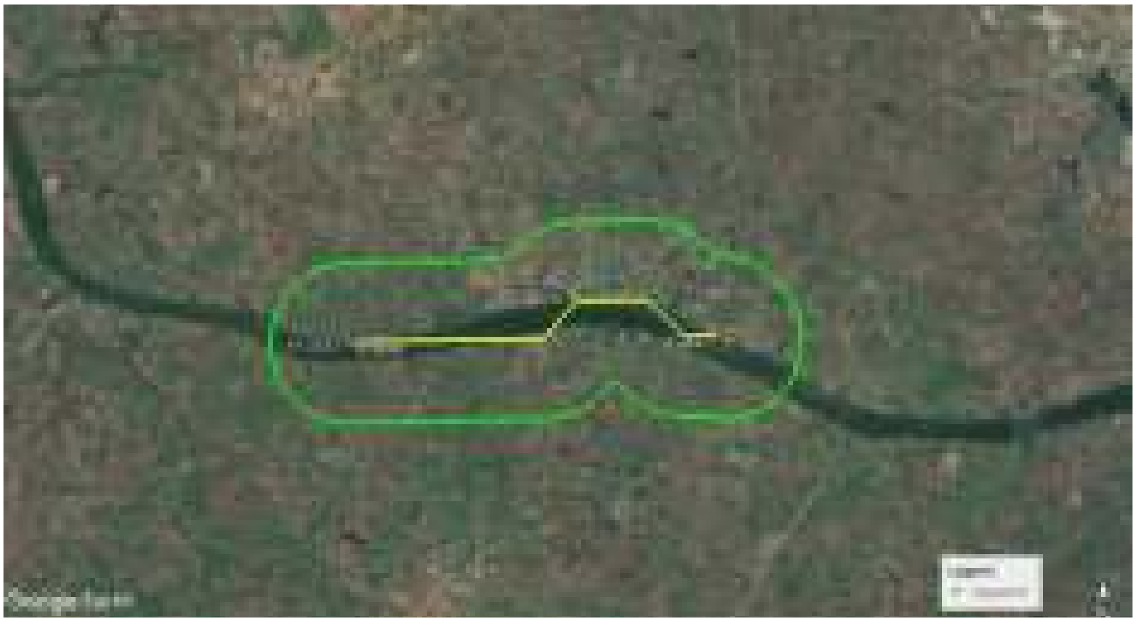
This segment is located downstream of Khujda village, Nanded district, Maharashtra (N 19° 00' 51.91", E 77° 29' 41.84" to N 19° 01' 11.00", E 77° 28' 16.55") at an elevation of 362 m and approximately 900 m away from the nearest human settlement. The river channel is mostly straight with some meanders towards the downstream area. The channel has a minimum and maximum width of 212 m and 271 m (Figure 4.23). Mud substratum characterizes the river in this segment at the start and the end. The water was 30% turbid at the beginning and 50% at the end, with a lean flow. The river's average depth in this segment is 4.18 m, ranging from 0.5 m to 7.5 m. The river in this segment is a medium sloped (>30-60°), fully covered with vegetation of trees, shrubs, and herbs.

Figure 4.23 Segment 13- Khujda village, Nanded district, Maharashtra

4.4.7 Sampling Segment 14

This segment is located downstream of Kondalwadi village, Nanded district, Maharashtra (N 18° 51' 14.78", E 77° 47' 59.10" to N 18° 52' 02.47", E 77° 45' 28.35") at 359 m elevation and 700 m from human settlement. The river is wide–single straight channel throughout this segment with a minimum and maximum width of 255 m and 337 m (Figure 4.24). A Mud substratum characterizes the river in this segment at the start and the end. The water has 50% turbidity at the start and is partially turbid, with 30% turbidity at the end, with a lean flow. The depth of the river in this segment is 5.4 m, ranging from 0.9 m to 7.1 m. The river in this segment has a medium slope (>30-60°) fully covered with vegetation of trees, shrubs, and herbs from the start to the end.

Figure 4.24 Segment 14 - Kondalwadi village, Nanded district, Maharashtra



4.4.8 Sampling Segment 15

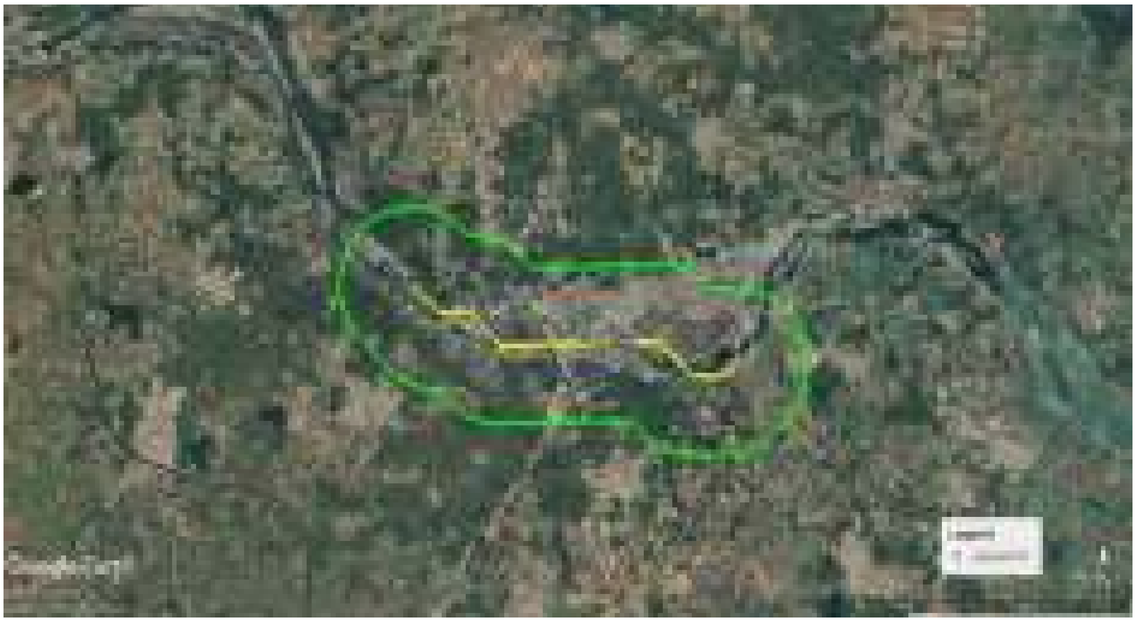
This segment is located downstream of Belur Khurd village (Maharashtra-Telangana border), Nanded district, Maharashtra (N 18° 49' 15.12", E 77° 52' 40.44" to N 18° 49' 01.56", E 77° 52' 45.32") at 335 m elevation, with the confluence of Manjra River (Godavari tributary) and 1000 m from human settlement. The river is wide–single straight channel throughout this segment with a minimum and maximum width of 238 m and 680 m (Figure 4.25). Mud and sand substratum characterizes the river in this segment at the start and muddy and sandy at the end. The water is 70% turbid at the beginning and 30% at the end, with a lean flow. The average depth in this segment is 3.05 m, ranging from 0.3 m to 7.1 m. The river in this segment has a medium slope (>30-60°) with partially exposed vegetation of herbs and grasses and a medium slope (>30-60°) at the end with partially exposed vegetation of trees, shrubs, herbs, and grass. Intensive Fishing activity was observed during the survey through gill nets, and the fishing community inhabit the river banks. Also, sun drying of the fish was carried out in this segment.

Figure 4.25
Segment 15-Kandakurthi village, Nizamabad district, Telangana

4.4.9 Sampling Segment 16

This segment is located downstream of the Sri Ram Sagar Reservoir (Pochampad Dam), Nizamabad district, Telangana (N 18° 58' 08.48", E 78° 28' 05.08" to N 18° 58' 08.42", E 78° 25' 45.50") at 395 m elevation and 300 m from human settlement. The river is a wide – braided channel throughout the segment with a minimum and maximum width of 57 m and 425 m. Rock with boulder substratum characterizes the river in this segment at the start and rock with boulders, cobbles, and pebbles at the end (Figure 4.26). The water is clear, with 0% turbidity at the beginning and 40% turbidity at the end, and had a lean flow due to Sri Ram Sagar Reservoir. The average depth in this segment is 1.19 m, ranging from 0.2 m to 3.6 m. The river at this segment has a medium slope (>30-60°) with partially exposed vegetation mainly herbs and grasses and a slope (90°) at the end with fully covered vegetation comprising trees, shrubs, herbs, and grass.

Figure 4.26 Segment 16- Parpelly village, Nizamabad district, Telangana



4.4.10 Sampling Segment 17

This segment is located downstream of the Gudchiriyal village, Nirmal district, Telangana (N 19° 03' 33.09", E 78° 52' 09.68" to N 19° 03' 02.50", E 78° 53' 01.20") at 221 m elevation and 1000 m from human settlement. The river in this entire segment is a wide braided channel, with a minimum and maximum width of 338 m and 493 m. Sand substratum characterizes the river in this segment at the start and rock with boulders at the end (Figure 4.27). The water has 20% turbidity at the beginning and 40% at the end, with a lean flow. The average depth in this segment is 3.05 m, ranging from 0.7 m to 6.5 m. The river at this segment has a medium slope (>30-60°) with partially exposed vegetation of herbs and grasses and a medium slope (>30-60°) at the end with partially exposed vegetation comprising shrubs, herbs, and grass.

Figure 4.27 Segment 17- Muniyal village, Nirmal district, Telangana

4.4.11 Sampling Segment 19

This segment is located downstream of Indaram village, Adilabad district, Telangana (N 18° 47' 19.53", E 79° 31' 08.28" to N 18° 46' 56.92", E 79° 31' 36.62") at 150 m elevation and 400 m from human settlement. The river is a wide–single straight channel throughout the segment with a minimum and maximum width of 537 m and 991 m throughout the segment, the river is characterized by mud with sand (Figure 4.28). The water has 20% turbidity at the start and 60% at the end, with a lean flow. The average depth in this segment is 3.26 m, ranging from 0.5 m to 6.1 m. The river in this segment has a medium slope (>30-60°) with partially exposed vegetation of herbs and grasses and a steep slope (90°) at the end with fully covered vegetation of trees, shrubs, and herbs and grass.

Figure 4.28 Segment 19- Sundilla village, Karimnagar district, Telangana

4.4.12 Sampling Segment 20

This segment is located downstream of Manddikunta village, Karimnagar district, Telangana (N 18° 48' 11.84", E 79° 57' 18.03" to N 18° 46' 35.00", E 79° 56' 24.36") at 130 m elevation and 400 m from human settlement. The river is a wide–braided channel throughout the segment with a minimum and maximum width of 658 m and 1710 m. Sand with mud substratum characterizes the river in this segment at the start, and sand with mud and rock at the end (Figure 4.29). The water is 20% turbid at the beginning and 70% at the end, with a lean flow. The average depth of the river in this segment is 2.3 m, ranging from 0.3 m to 7.4 m. The river in this segment has a steep slope (90°) with partially exposed vegetation of herbs and grasses and a high slope (90°) at the end with fully covered vegetation of trees, shrubs, herbs, and grass.

Figure 4.29 Segment 20- Madigadda pump house, Kannepalli village, Jayashankara Bhupalapally district, Telangana.

4.4.13 Sampling Segment 21

This segment is located downstream of Neelampalle village, Somnoor river confluence, Warangal district, Telangana (N 18° 39' 37.19”, E 80° 18' 36.12” to N 18° 41' 26.79”, E 80° 18' 00.15”) at 108 m elevation and 500 m from human settlement. The river in this segment is a wide–-meander at the start and a wide-braided channel at the end, with a minimum and maximum width of 774 m and 901 m. Mud substratum characterizes the river in this segment at the start, and sand with rock at the end (Figure 4.30). The water has 40% turbidity at the beginning and 20% at the end, with a lean flow. The average depth in this segment is 1.62 m, ranging from 0.1 m to 3.5 m. The river in this segment has a steep slope (90°) with partially exposed vegetation of herbs and grasses and a steep slope (90°) at the end with partially exposed vegetation of trees, shrubs, herbs, and grass.

Figure 4.30 Segment 21- Neelampalle village, Warangal district, Telangana

4.4.14 Sampling Segment 23

This segment is located downstream of Ramanakkapeta village, Mulugu district, Telangana (N 18° 12' 06.81", E 80° 36' 51.46" to N 18° 11' 22.92", E 80° 37' 53.48") at 600 m elevation and 76 m from human settlement. The river is a wide–braided channel throughout the segment with a minimum and maximum width of 3019 m and 3691 m. Sand substratum characterizes the river in this segment at the start, and sand with mud at the end (Figure 4.31). The water is clear, with 0% turbidity at the beginning and 40% at the end, having a lean flow. The average depth in this segment is 1.19 m, ranging from 0.1 m to 2.8 m. The river in this segment has a medium slope (>30-60°) with partially exposed vegetation of herbs and grasses and a steep slope (90°) at the end with partially exposed vegetation of trees, shrubs, and herbs and grass. Chilli farming was observed during the survey in this river segment, and red chili was being dried on the river bank.

Figure 4.31 Segment 23-Wagagudem PR village, MCR Mirchi land, Mulugu district, Telangana

4.4.15 Sampling Segment 24

This segment is located downstream of Chinnaravigundem village, Manuguru intake well park, BhandradriKothagudem district, Telangana. (N 17° 56' 24.88”, E 80° 52' 41.82” to N 17° 56' 14.69”, E 80° 53' 31.93”) at 70 m elevation and 400 m from human settlement. The river is a wide–braided channel throughout the segment with a minimum and maximum width of 1118 m and 2163 m. Sand substratum characterizes the river in this segment at the start, and sand with mud at the end (Figure 4.32). The water was 40% turbidity at the beginning and 40% at the end, with a lean flow. The river's average depth in this segment is 3.8 m, ranging from 1.8 m to 6.4 m. The river in this segment has a medium slope (>30-60°) with partially exposed vegetation of herbs and grasses and alow slope (Flat) at the end with partially exposed vegetation of trees, shrubs, and herbs and grass. The river bed is dry in this segment, and watermelon is being grown.

Figure 4.32 Segment 24- Watermelon farming on Godavari River bed, Annaram, BhandradriKothagudem, Telangana

4.4.16 Sampling Segment 25

This segment is located downstream of the Pinapally village, Kinnerasani river confluence, Bhadrachalam district, Andhra Pradesh (N 17° 38' 43.74", E 80° 55' 44.52" to N 17° 38' 28.62", E 80° 53' 35.17") at 60 m elevation and 800 m from human settlement. The river is a wide–braided channel throughout the segment with a minimum and maximum width of 1040 m and 1274 m. Sand substratum characterizes the river in this segment at the start and sand with mud and rock at the end (Figure 4.33). The water is 50% turbid at the beginning and 60% at the end, with a lean flow. The average depth in this segment is 2.85 m, ranging from 2 m to 3.4 m. The river at this segment has a steep slope (90°) with partially exposed vegetation of herbs and grasses and a medium slope (>30-60°) at the end with fully exposed vegetation of trees, shrubs, herbs, and grass.

Figure 4.33 Segment 25-Pinapally village, Kinnerasani river confluence, Bhadrachalam district, Andhra Pradesh

4.4.17 Sampling Segment 26

This segment is located downstream of Chinnapolipaka village, Godavari- Sabri Sangam, Khammam district, Telangana (N 17° 36' 00.76", E 81° 07' 42.73" to N 17° 37' 05.94", E 81° 06' 08.61") at 50 m elevation and 800 m from human settlement. The river in this segment is a wide–single straight channel at the start and single-widemeander at the end, with a minimum and maximum width of 750 m and 1275 m. Sand and mud substratum characterize the river in this segment at the start, and sand with rock at the end (Figure 4.34). The water has 40% turbidity at the beginning and 30% at the end, with a lean flow. The average depth in this segment is 2.3 m, ranging from 0.4 m to 5.3 m. The river in this segment has a steep slope (90°) with partially exposed vegetation of herbs and grasses and a medium slope (>30-60°) at the end with partially exposed vegetation of trees, shrubs, herbs, and grass. The river bed in this segment is dry and it is also prone to sand mining.

Figure 4.34 Segment 26- Vinjaram Village, Khammam District, Andhra Pradesh

44.4.18 Sampling Segment 27

This segment is located inside the Papikonda National Park, Papi Hills, Alluri Sitharama Raju district, Andhra Pradesh (N 17° 26' 20.10", E 81° 33' 24.18" to N 17° 26' 45.34", E 81° 32' 29.29") at elevation of 40 m and 200 m away from human settlement. The river is a wide meander throughout the segment, with a minimum and maximum width of 574 m and 789 m. Sand, mud, and rock substratum characterize the river in this segment at the start, and mud with sand at the end (Figure 4.35). The water has 20% turbidity at the beginning and 30% at the end, with a lean flow. The average depth in this segment is 12.9 m, ranging from 1.6 m to 26.1 m. The river in this segment is a medium slope (>30-60°) with partially exposed vegetation of trees, herbs, and grasses and a medium slope (>30-60°) at the end with partially exposed vegetation of trees, shrubs herbs, and grass.

Figure 4.35 Segment 27- Papikonda National Park, Alluri Sitharama Raju district, Andhra Pradesh

4.4.19 Sampling Segment 28

This segment is located upstream of Rajahmundry district, Andhra Pradesh (N 17° 04' 47.67”, E 81° 44' 57.09” to N 17° 04' 25.21”, E 81° 42' 43.03”) at 50 m elevation. The river in this segment is a wide–braided channel at the start and a wide-meander at the end, with a minimum and maximum width of 2541 m and 3844 m. Sand with mud substratum characterizes the river in this segment at the start, and sand, and mud with rock at the end (Figure 4.36). The water is 20% turbidity at the beginning and 40% at the end, with a lean flow. The average depth in this segment is 2.6 m, ranging from 0.9 m to 8.6 m. The river in this segment has a steep slope (90°) with partially exposed vegetation of herbs and grasses and a medium slope (>30-60°) at the end with partially exposed vegetation of trees, shrubs, herbs and grass. In this river segment, large-scale fishing activity was observed by gill nets and large fishing boats.

Figure 4.36 Segment 28–Mullukallanka village, East Godavari district, Andhra Pradesh

4.4.20 Sampling Segment 29

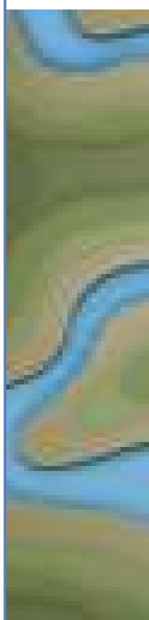
This segment is located downstream of Vengeswarapuram village, Yanam, Puducherry UT (N 16° 43' 33.33'', E 81° 58' 03.84'' to N 16° 43' 31.59'', E 81° 59' 14.98'') at 11 m elevation and 200 m from human settlement. The river is a wide–braided channel throughout the segment with a minimum and maximum width of 1366 m and 2817 m. Sand characterizes the river substratum with mud (Figure 4.37). The water is 30% turbid at the start and the end of the segment, with a lean flow. The river is this segment has a medium slope (>30-60°) with partially exposed vegetation of herbs and grasses and a medium slope (>30-60°) at the end with partially exposed vegetation of trees, shrubs, herbs, and grass. This is an estuarine area of the river segment and large fishing vessels were observed.

Figure 4.37 Segment 29– Vengeswarapuram village, Yanam, Puducherry

Table 4.2 Details of Sampling Segments in Godavari Riverscape, India

Sampling Segment	Zone	State	Location	GPS Location	
				Start Point	End Point
1			Beze, Nashik District	19 59 49.55 N 73 35 40.70 E	20 00 13.71 N 73 35 18.68 E
3			Chandgavhan, Ahilyanagar District	19 53 15.29 N 74 25 46.53 E	19 52 24.43 N 74 25 54.29 E
6			Gulaj Dam, Aurangabad District	19 22 43.34 N 75 35 12.94 E	19 22 36.01 N 75 37 06.17 E
8	Upper	Maharashtra	Dhalegao, Parbhani District	19 14 42.16 N 76 20 58.46 E	19 12 46.93 N 76 21 47.47 E
12			Rahati, Parbhani District	19 07 29.51 N 77 10 05.55 E	19 06 36.79 N 77 13 34.04 E
13			Khujda, Nanded District	1900 46.07 N 77 29 41.84 E	19 01 11.00 N 77 28 16.50 E
14			Kondalwadi, Nanded District	18 51 14.78 N 77 47 59.10 E	18 52 02.47 N 77 45 28.35 E
15			Aloor, Nizamabad District	18.830568 N 77 29 41.84 E	18.824817 N 77.890943 E
16			Parpalle, Nizamabad District	18 58 08.48 N 78 28 05.08 E	18 58 08.42 N 78 25 45.50 E
17	Middle	Telangana	Gudchiriyal, Nirmal District	19 03 33.09 N 78 52 09.68 E	19 03 02.50 N 78 53 01.20 E
19			Indaram, AdilabadDistrict	18 47 19.53 N 79 31 08.28 E	18 46 56.92 N 79 31 36.62 E
20			Manddikunta, Karimnagar District	18 48 11.84 N 79 57 18.03 E	18 46 35.00 N 79 56 24.36 E
21			Neelampalle, Warangal District	18 39 37.19 N 80 18 36.12 E	18 41 26.79 N 80 18 00.15 E
23		Telangana	Ramanakkapeta, Mulugu District	18 12 06.81 N 80 36 51.46 E	18 11 22.92 N 80 37 53.48 E
24			Chinnaravigundem, Mulugu District	17 56 24.88 N 80 52 41.82 E	17 56 14.69 N 80 53 31.93 E
25	Lower		Pinapally, Bhadrachalam District	17 38 43.74 N 80 55 44.52 E	17 38 28.62 N 80 53 35.17 E
26		Andhra Pradesh	Chinnapolipaka, Khammam District	17 36 00.76 N 81 07 42.73 E	17 37 05.94 N 81 06 08.61 E
27			Papikonda National Park, Raju District	17 26 20.10 N 81 33 24.18 E	17 26 45.34 N 81 32 29.29 E
28			Gandi Pochamma Ammavari Temple, Rajahmundry District	17 04 47.67 N 81 44 57.09 E	17 04 25.21 N 81 42 43.03 E
29			Vengeswarapuram, Yanam District	16 43 33.33 N 81 58 03.84 E	16 43 31.59 N 81 59 14.98 E

	Elevation (msl)	Width (m)		Depth Avg. (m)		Flow (m/s)	
		Max.	Min.	Max.	Min.	Max.	Min.
	615	80	32	2.42	0.3	2.4	0.3
	516	259	170	5.06	0.4	0.9	0.3
	410	155	9	1.31	0.16	00	00
	384	348	99	6.38	0.68	00	00
	347	348	228	2.75	2.22	00	00
	362	271	212	6.7	3.4	00	00
	359	337	255	6.7	3.4	00	00
	363	680	238	4.54	2.5	00	00
	395	425	57	2.74	0.3	00	00
	221	493	338	4.8	1.3	00	00
	150	991	537	4.6	2.4	00	00
	130	1710	658	5.06	0.86	00	00
	108	901	774	3.18	1.04	00	00
	76	3691	3019	2.12	0.26	00	00
	70	2163	1118	4.31	2.43	00	00
	60	1274	1040	4.3	2.4	00	00
	50	1275	750	3.7	0.9	00	00
	40	789	574	15.1	9.3	00	00
	50	3844	2541	7.5	1.0	00	00
	11	2817	1366	-	-	00	00



References

Abbasnia A, Yousefi N, Mahvi AH, Nabizadeh R, Radfard M, Yousefi M and Alimohammadi M (2019) Evaluation of groundwater quality using water quality index and its suitability for assessing water for drinking and irrigation purposes: A Case study of Sistan and Baluchistan province (Iran). Human and Ecological Risk Assessment: An International Journal 25(4), 988-1005.

Hengade N and Eldho TI (2019) Relative impact of recent climate and land cover changes in the Godavari river basin, India. Journal of Earth System Science 128(4), 94-105.

Himayoun D and Roshni T (2020) Geomorphic changes in the Jhelum River due to an extreme flood event: a case study. Arabian Journal of Geosciences, 13(1), p.23.

Ibitoye MO (2021) A remote sensing-based evaluation of channel morphological characteristics of part of lower river Niger, Nigeria. SN Applied Sciences 3(3), 340-351.

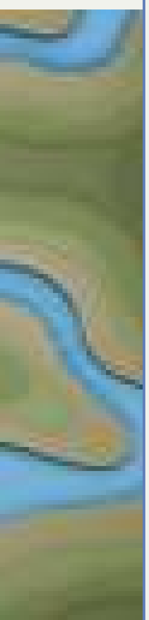
Kharake AC and Raut VS (2021) An assessment of water quality index of Godavari River water in Nashik city, Maharashtra. Applied Water Science11(6), 101-112.

Kong D, Latrubesse EM, Miao C and Zhou R (2020) Morphological response of the Lower Yellow River to the operation of Xiaolangdi Dam, China. Geomorphology 350, 106931.

Nath A and Ghosh S (2022) Meandering rivers' morphological changes analysis and prediction–a case study of Barak River, Assam. H2Open Journal, 5(2), 289-306.

Pachecho FAL and Fernandes LFS (2020) Watersheds, anthropogenic activities and the role of adaptation to environmental impacts. Water 12(12), 3451.

Yousefi S, Pourghasemi HR, Hooke J, Navratil O and Kidova A (2016) Changes in morphometric meander parameters identified on the Karoon River, Iran, using remote sensing data. Geomorphology 271, 55-64.



05

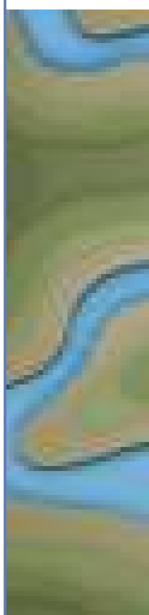
FLORAL ASSEMBLAGE IN GODAVARI RIVER

05

FLORAL ASSEMBLAGE IN GODAVARI RIVER

Abstract

Riverine vegetation conservation is critical for the management of the river ecosystem yet studies to assess the status of riverine vegetation in the Godavari River are lacking. We assessed the status of trees, shrubs, herbs, grasses, climbers and sedges along with the Importance Value Index (IVI), and above ground biomass of trees in the Godavari River. A total of 242 plants species including 64 trees (26%), 20 shrubs (8%), 101 herbs (42%), 25 grasses (10%) 28 climbers (12%), and Four sedges (2%) were recorded in the Godavari River. Among these 25 % of plants were exotic with the majority of them being Tropical America in origin. The average density of trees, shrubs, herbs, grasses, climber and sedges was 98.50±4.11 indi/ha, 88.88±5.29 indi/ha, 7698.48±115.13 indi/ha, 2341.23±63.47 indi/ha, 182.37±21.03 indi/ha and 77.05±21.97 indi/ha, respectively. However, Prosopis juliflora, (42.61±12.85 indi/ha) was the most dominant species among the trees, Lantana camara among the shrubs (99.92±26.73 indi/ha), Alternanthera sessilis among herbs (1791.83±43.52 indi/ha), Cynodon dactylon among the grasses (747.74±36.76 indi/ha), Clitoria ternatea among the climbers (61.55±11.71 indi/ha), and the Cyperus rotundus among the sedges were recorded most abundant species with 47.87±10.35 indi/ha. Additionaly a total of 48 invasive plant species were recorded during the survey. The trees in the Godavari River sustain an average above-ground biomass per hectare of 6.98±0.53 Mg/ha (Mega gram/hectare). The present information could serve as baseline information to assess the adverse impact of anthropogenic pressure on the riparian vegetation of the Godavari River.



5.1 Introduction

Riverine vegetation is crucial for maintaining the ecological balance of the river ecosystem. Riverine vegetation contributes to bank stability and helps in the recharging of aquatic ecosystems thereby influencing the stream flow (Eaton et al., 2004). Riverine vegetation inhibits the effect of water on soil and minimizes soil erosion through the interaction of soil gradient and vegetation cover (Zhang et al., 2019). The leaves and organic matter from riverine vegetation help in the nutrient recycling of the aquatic environment. The canopy of riverine vegetation is vital for the optimum light penetration for streambed thereby influencing the microclimate, wind, thermal regime, as well as primary productivity of the riverine ecosystems (Richardson and Moore, 2010). The riverine vegetation also acts as a barrier against highland runoff, playing a crucial role in infiltration, intercepting, and depositing soil particles to prevent erosion and stabilize riverbanks (Hould-Gosselin et al., 2016). The riverine vegetation maintains the food chain by serving as the main food source for many aquatic invertebrates, which in turn, provide food sources for many aquatic and terrestrial species (Bilby, 1988, Swanson et al., 1982, Cummins, 1980). Additionally, riverine vegetation serves as a corridor for terrestrial birds and animals, including otters for rest and refuge (Rajpar et al., 2022).

Anthropogenic activities particularly those driven by urbanization, agriculture, industrialization, climate change etc., have profound effects on the delicate balance of riverine vegetation. Rapid urbanization often leads to habitat loss and fragmentation, as infrastructure development encroaches upon natural riverine areas. Urban runoff, containing heavy metals, oil, and nutrients, degrades the water quality, causing phytotoxicity in plants as they absorb these harmful chemicals through their roots resulting in poor growth, dying seedlings and dead spots on leaves (Alengebawy et al., 2021). When untreated sewage enters a river system it is broken down by water bacteria, producing ammonia; yet, this oxygen-consuming process causes harm to river vegetation by reducing oxygen level (Okereke et al., 2016). The extensive use of pesticides in agriculture contributes to increasing nitrate levels in rivers and stimulating excessive growth of algae through the process of eutrophication. This, in turn, inhibits the growth of aquatic and riverine plants by obstructing sunlight and reducing oxygen (El-Sheekh et al., 2021). When industries release heated water into rivers from thermal power plants, it increases the temperature of the water bodies and disrupts the enzymatic functioning in plants (Kalair et al., 2021). Additionally, the release of detergents containing phosphates into water bodies results in phosphate enrichment. When riverine plants absorb water enriched with phosphates, it leads to growth retardation, cell destruction, and other detrimental effects (Nagajyoti et al., 2010). Many aquatic plants have specific pH ranges within which they thrive, and deviations from these optimal conditions can lead to stress, reduced growth, and even death of the plants. The discharge of organic wastes into water bodies alters the pH of the water. Extremely high or low pH leads to nutrient element unavailability, ion imbalances, damage to plant membranes, and osmotic stress, thereby inhibiting nutrient absorption and thus affecting plant growth, photosynthesis, and plant disease resistance (Guo et al., 2015; Chen et al., 2019; Zhang et al., 2020).

Godavari River is the largest river system of Peninsular India (1465 km) and is considered the second-longest river in the country after the Ganges. Godavari basin encompasses a diverse range of forest types, and several endemic species of plants such as *Phlebophyllum jeyporensis, Heterostemma deccanense, Toxocarpus roxburghii, Glochidion tomentosum, Phyllanthus narayanaswamii, Leucas diffusa, Acacia campbelli, Mimosa barberi, Atylosia cajanifolia, Wendlandia gamble, Vanilla wightiana* etc (NRCD-WII, 2022, Reddy et al., 2008). However, the Godavari River is threatened by several anthropogenic activities such as pollution, water abstraction, construction of dams, deforestation and natural factors like climate change impacting the status and distribution of the riverine vegetation (Bhattacharya et al., 2012; Das et al., 2022; Singh et al., 2022; Navasakthi et al., 2023; Katharanjan et al., 2023 and Bharambe et al., 2023). Assessment of the status and distribution of the riverine vegetation could help in their conservation and management in the face of increasing anthropogenic pressure.

The cumulative impact of these anthropogenic activities poses a serious threat to the delicate balance of river ecosystems, emphasizing the urgent need for sustainable practices and conservation efforts. A comprehensive analysis of the literature revealed that a major part of Godavari River is unexplored and knowledge of the floral wealth is not fully known. Therefore, we carried out a rapid assessment of the status of riverine vegetation including trees, shrubs, herbs, grasses, climbers and sedges along with the important value index (IVI), and above ground biomass of trees to ensure the long-term sustainability of the Godavari River and its associated ecosystems.

5.2 Methods of Assessment

5.2.1 Vegetation Survey

Data on the riverine vegetation of the Godavari River was collected by laying a total of 79 transects during the surveys (Figure 5.1). On each transect trees, shrubs, herbs, grasses, climber and sedges were sampled by laying five circular plots

Figure 5.1 Vegetation sampling in the Godavari River

maintaining a minimum distance of 200 m between two consecutive plots.

Tree species were recorded along with their abundance, height, and girth at breast height (GBH) in a 10 m radius (314 m^2) plot. Shrub richness and abundance were assessed by laying a 3 m^2 plot (Misra,1968). Data on the richness and abundance of herbs, grass, and climbers were recorded by laying four 1 m^2 plots randomly within a tree plot. The unidentified plant samples were collected from the field by selecting representative specimens from each zone along the Godavari River. Each sample was carefully labeled with its location, date, and habitat information, then pressed and dried using a plant press. The dried specimens were later identified and verified herbarium references, relevant botanical literatureand online sources viz., https://identify.plantnet.org/, https://www.worldfloraonline.org/, https://plant.id/, https://identifythatplant.com/plant-id-resources/plant-id-websites/.

5.2.2 Vegetation Analysis

The phytosociological parameters such as richness, diversity, frequency and density were computed through conventional methods following Pandey and Shukla (2001; 2003; and 2005). Additionally Importance Value Index (IVI) of all tree species was calculated to determine the dominant tree species in the area. IVI was computed by summing up relative density (RDE), relative frequency (RFO), and relative dominance (RDO). The Shannon Diversity Index (also known as the Shannon-Wiener Index) were use for quantifying the diversity of species within the community. The Shannon Diversity Index is a quantitative measure that indicates the number of different types (such as species) present in a dataset (community). These indices statistically represent various aspects of biodiversity, including richness, evenness, and dominance.

$$\textit{Shanon's diversity } (H) = -\sum_{k=1}^{s} (p_i * \ln P_i)$$

Where,
H = Shannon diversity index
Pi = Proportion of ith species in the population
s = Total number of species in the area
I = number of individual species.

$$\textit{Density } (D) = \frac{n}{(\textit{Area of plot})} \times 10000 \ (\textit{individual } \mathrm{ha}^{-1})$$

n = number of individuals of ith tree species

$$\textit{Relative Density (RDE)} = \frac{\text{Density of an } i^{th} \text{ species}}{(\textit{Total density of all species})} \text{ X } 100$$

$$\textit{Frequency of occurrence (FO)} = \frac{\text{number of plots in which } i^{th} \text{ species occur}}{\textit{total number of plots}} \text{ X } 100$$

$$\textit{Relative Frequency of accurrence (FO)} = \frac{\text{FO of } i^{th} \text{ species}}{\text{total FO of all species}} \text{ X } 100$$

$$\textit{Relative Dominance (RDO)} = \frac{\text{Basal area of } i^{th} \text{ species}}{\text{total basal area of all species}} \text{ X } 100$$

$$\textit{Basal Area} = \frac{\pi \text{ gbh}^2}{4}$$

$$\textit{Importance Value Index (IVI)} = RD + RF + RDO$$

5.2.3 Above Ground Biomass and Carbon Stock

Above Ground Biomass is an important variable for evaluating carbon sequestration and the carbon balance capacity of forest ecosystems. The above-ground biomass of trees in the Godavari River was calculated using the species-specific volume equation developed by Forest Survey India (2016). The estimated volume was multiplied by the specific gravity to assess the above-ground biomass. A similar approach has been used by previous studies in the moist deciduous Sal-dominated Forest (Baishya and Barik, 2011; Banik et al., 2018). Tree species for which the volume equation was not present, the volume equation developed by Chambers et al. (2001) was used. Volume equations and wood-specific gravity used to calculate the above-ground biomass are given in Appendix 5.1.

The carbon stock (Mg Cha^{-1}) was quantified by assuming that carbon constitutes 50% of the above-ground biomass of each living tree, following the IPCC Good Practice Guidance for Land Use, Land-Use Change, and Forestry (Penman et al., 2003).

5.3 Vegetation of Godavari River

A total of 242 plant species including 64 trees (26%), 20 shrubs (8%), 101 herbs (42%), 25 grasses (10%), 28 climbers (12%), and four sedges (2%) were observed from the Godavari River (Figure 5.2). Our analysis indicated presence of 61 (25%) exotic species and 181 (75%) native species. Within the exotic plant types, herbs (40%), followed by climbers (33.3%), trees (15%), shrubs (8.3%), and grasses (3.3%). Notably, there are no invasive sedges among the exotic species. The introduction of exotic species, primarily from Tropical America (20%) followed by Central and South America (11.7%), with the remainder from various other regions worldwide (Figure 5.5).

A total of nine aquatic plants belonging to seven family viz., Amaranthaceae, Boraginaceae, Araceae, Polygonaceae, Pontederiaceae, Typhaceae, and Cyperaceae were recorded in the Godavari River. Among the nine aquatic plants one were sedges, one grass and remaining were herbs. Of the recorded species of plants, one species were Data Deficient (DD), one Near Threatened (NT), one Vulnerable (VU), 91 species were Least Concern (LC) and 148 were belongs to Not Evaluated (NE) (Table 5.1).

Table 5.1 Summary of floral assemblage recorded in Godavari River

Parameter	Upper Zone	Middle Zone	Lower Zone	Overall
Families	52	28	41	57
Order	28	19	21	30
Genera	155	70	109	197
Species	192	77	121	242
Trees	44	15	36	64
Shrub	18	8	9	20
Sedges	3	1	2	4
Herb	85	38	54	101
Grass	19	12	14	25
Climber	23	3	6	28
Aquatic	8	3	3	9
Terrestrial	184	74	118	233
Annual	61	29	45	73
Perennial	131	48	76	169
Exotic	56	15	17	61
Native	136	62	104	181
Vulnerable (VU)	1	0	0	1
Near Threatend (NT)	1	0	0	1
Least Concern (LC)	70	31	47	91
Not Evaluted (NE)	119	46	73	148
Data Deficient (DD)	1	0	1	1

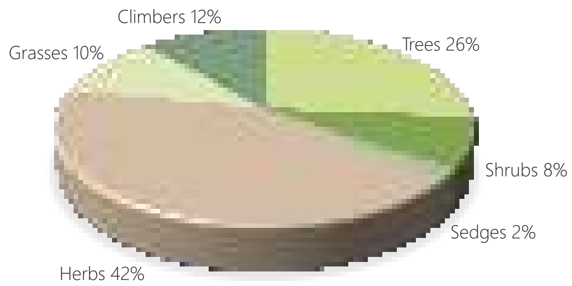


Figure 5.2
Percentage of trees, shrubs, grass, herbs and climbers recorded in the Godavari River

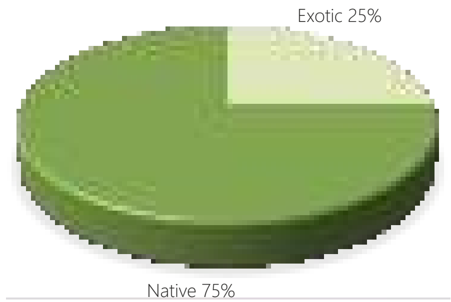


Figure 5.3
Percentage composition of native and exotic plants species in Godavari River

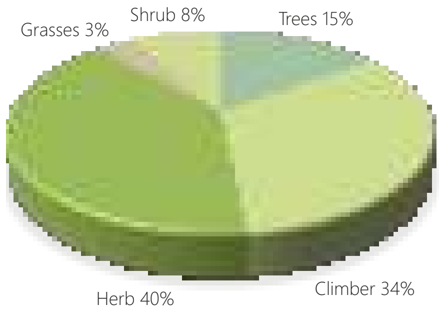


Figure 5.4:
Distribution of exotic plants by type, showing the percentage of each category (Trees, Shrubs, Herbs, Grasses, Climbers) in Godavari River

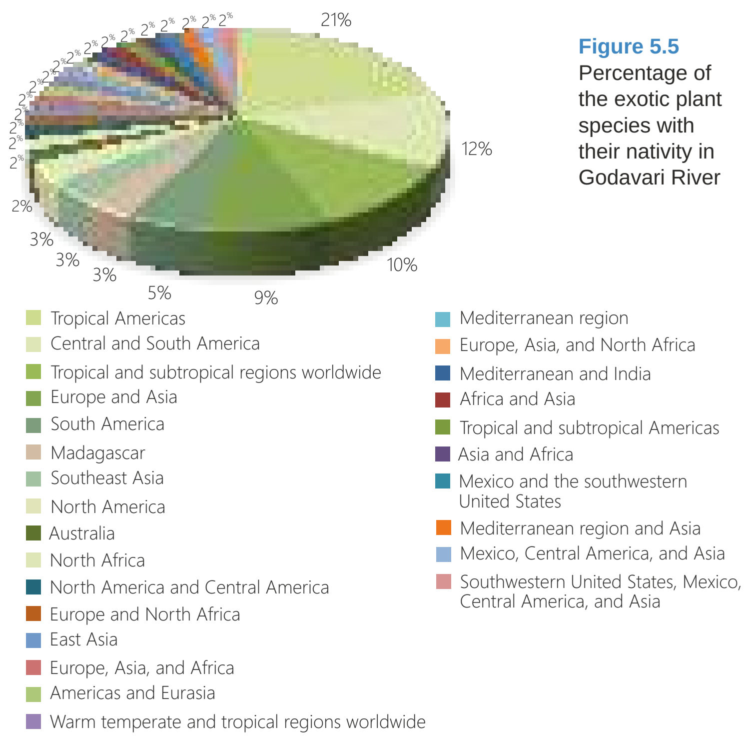


Figure 5.5
Percentage of the exotic plant species with their nativity in Godavari River

5.3.1 Trees

A total of 64 tree species representing 51 genera and 29 families were recorded in the Godavari River (Table 5.2). Maximum number of tree species belong to the families Fabaceae (n=12 species) followed by Moraceae and Mimosaceae (n=6 and 5 species respectively). A total 13 families were represented by only one species (Figure 5.6). Majority of the recorded trees species were evergreen (n=35 species) and remaining were deciduous (n=29 species). About 14% (n=9 species) were invasive to the Godavari basin. Two species viz., *Terminalia pallida* and *Aegle marmelos* have been categorised as threatened and vulnerable respectively in the IUCN Red List of Threatened Species. The details of the tree species recorded in the Godavari River during the survey are presented in Table 5.2.

A comparison of the tree species richness among upper, middle and lower zone revealed that the richness of the trees was highest in upper zone (n=44 species) followed by lower zone (n=36 species). However, the least richness was observed in the middle zone (n=15). The diversity of the trees was highest in upper zone (H'=2.95) followed by lower zone (H'=1.88) and middle zone (1.57). Fabaceae was dominant family in upper zone however, Mimosaceae family was dominating in middle and lower zones of the Godavari River (Figure 5.6). The Upper, middle and lower zone of the Godavari River consisted of eight, one and two exotic species respectively. Richness of native tree species, deciduous and evergreen tree were higher in upper zone of the Godavari River. The details of the tree species recorded in the Godavari River during the survey are presented in Appendix 5.2

Table 5.2 Summary of tree species found in Godavari River

Parameter	Trees			
	Upper Zone	Middle Zone	Lower Zone	Overall
Species	44	15	36	64
Family	21	9	23	29
Order	13	6	13	16
Genus	34	13	34	51
Diversity (Shannon's H')	2.95	1.57	1.88	2.66
Near Threatened (NT)	1	0	0	1
Data deficient (DD)	1	0	1	1
Not Evaluate (NE)	10	2	10	18
Least concern (LC)	31	13	25	43
Vulnerable (VU)	1	0	0	1
Native	36	14	34	55
Exotic	8	1	2	9
Annual	0	0	0	0
Perennial	44	15	36	64
Deciduous	18	6	14	29
Evergreen	26	9	22	35

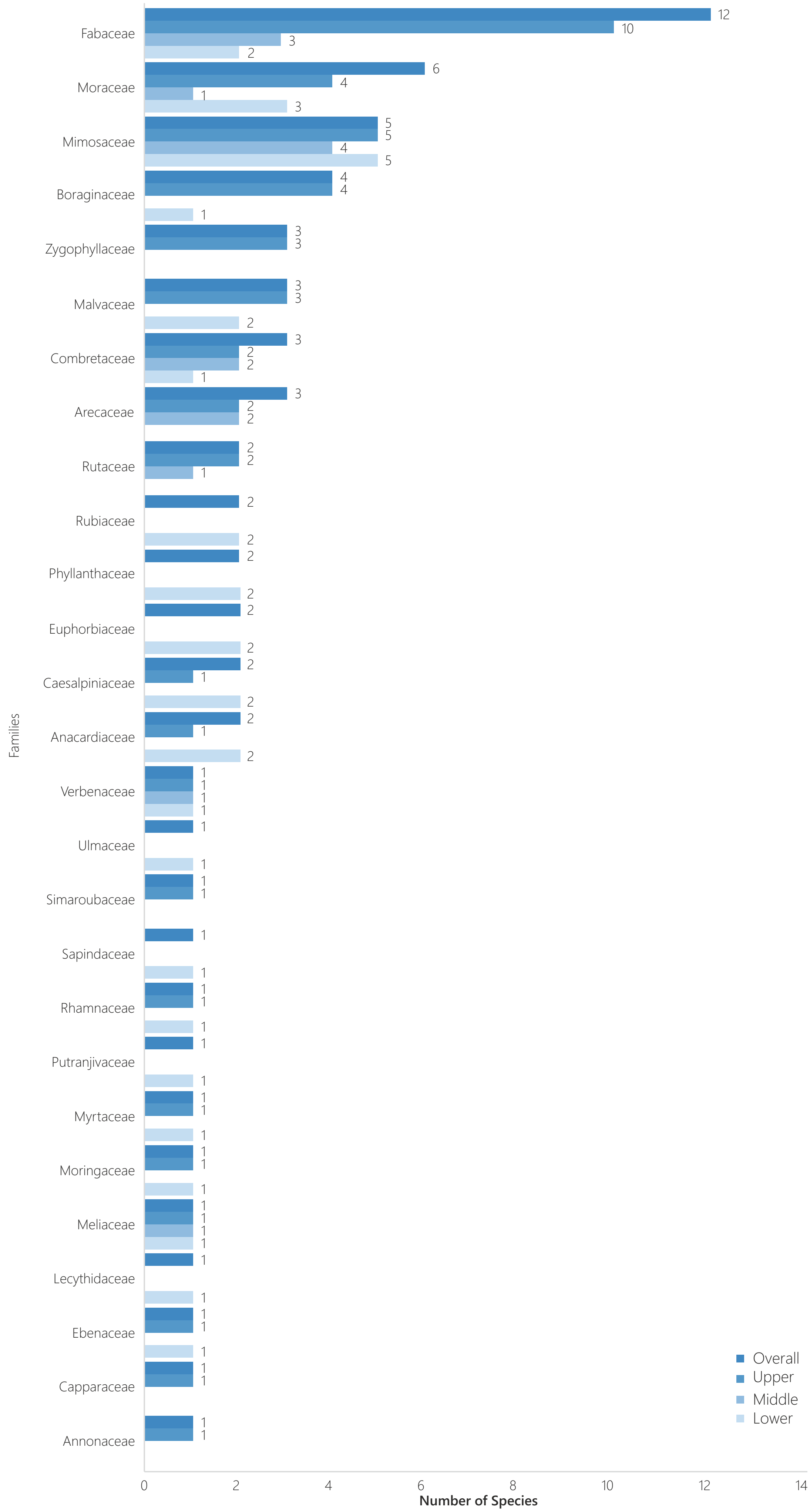
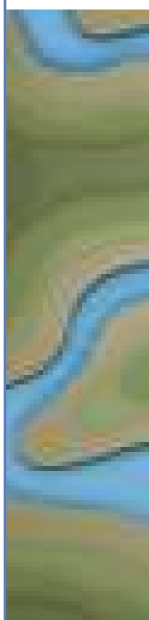


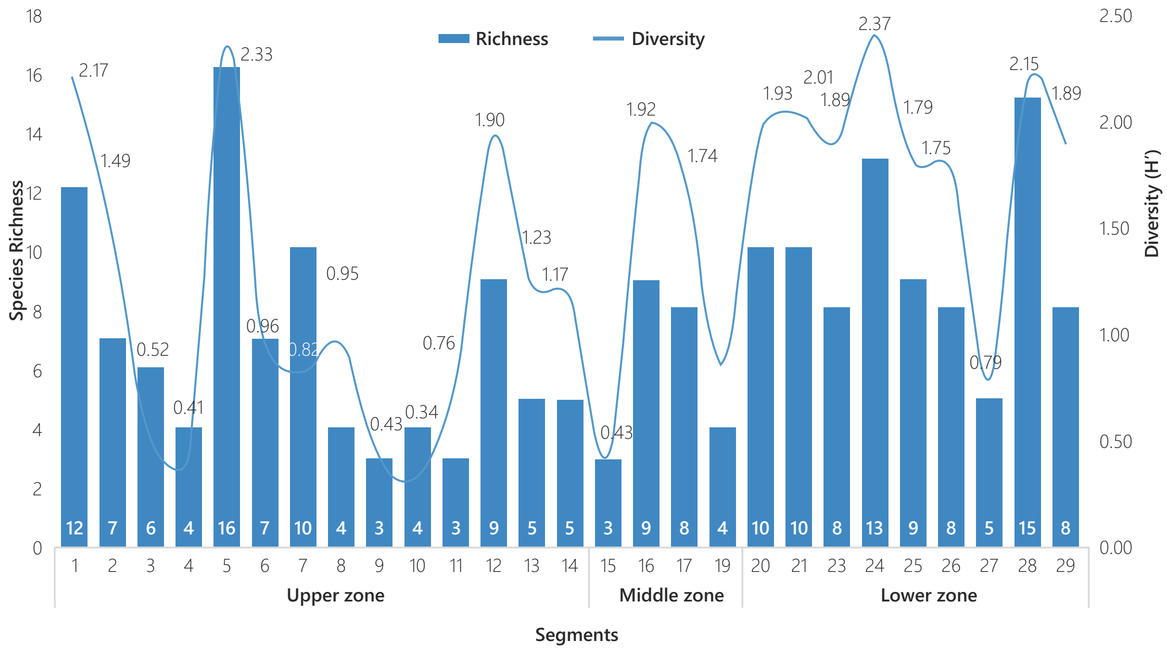
Figure 5.6
Number of species recorded in various families of trees in Godavari River



5.3.1.1 Richness and diversity of trees at various segments

Maximum richness of tree species was observed at segment 5 (n=16 species) followed by segment 28 (n=15 species), segment 24 (n=13 species), segment 1 (n=12 species), segment 7, 20, and 21 (n= 10 species each). Least richness was observed in segment 9, 11 and 15 (n= 3 species). Diversity of trees was observed maximum at segment 24 (*H'*= 2.37) followed by segment 5 (*H'*= 2.33), and segment 1 (*H'*=2.17). Segment 10, supported the lowest diversity of the trees (*H'*= 0.34). Figure 5.7 highlight the richness and diversity of trees at various sampling segment.

Figure 5.7 Richness and diversity of trees at various segments in Godavari River



5.3.1.2 Abundance of trees

The overall tree density in Godavari River was 98.50±4.11 ha^{-1}. *Prosopis juliflora* was the dominant species (42.61±12.85 ha^{-1}) and it was followed by *Borassus flabellifer* (6.28±3.44 ha^{-1}), *Acacia nilotica* (5.92±2.11 ha^{-1}), *Azadirachta indica* (5.02±1.63 ha^{-1}) and *Ficus racemosa* (3.50±1.31 ha^{-1}). *Aegle marmelos, Annona reticulate, Artocarpus heterophyllus, Balanites aegyptiaca, Bridelia retusa, Capparis divaricate, Cassia javanica, Cordia dentata, Delonix regia, Ficus benghalensis, Haldina cordifolia, Peltophorum pterocarpum, Phyllanthus emblica, Sesbania sesban, Spondias indica, Terminalia arjuna, Terminalia pallida*, and *Vachellia farnesiana* were with lowest density (0.09±0.09 ha^{-1}) in the Godavari River. These species were encounter only once during the survey. Density of the tree species recorded in the Godavari River is highlighted in Table 5.3.

Upper zone of the Godavari River supported higher density of trees (119.15±6.14 ha^{-1}) than the lower (85.86±6.41 ha^{-1}) and middle zone (66.35±8.47 ha^{-1}). In upper and middle zone, *Prosopis juliflora* was the most abundant species with 74.56±6.58 ha^{-1} and 40.34±8.67 ha^{-1} respectively, followed by *Acacia nilotica*, *Azadirachta indica* and *Pongamia pinnata* (Table.5.2). *Acacia catechu, Aegle marmelos, Annona reticulata, Balanites aegyptiaca, Capparis divaricate, Cassia javanica, Cordia dentata, Delonix regia, Diospyros melanoxylon, Ficus benghalensis, Limonia acidissima, Sesbania sesban, Syzygium cumini, Terminalia pallida*, and *Vachellia farnesiana* shows least density in upper zone with 0.19±0.19 ha^{-1} with each species. In middle zone *Acacia catechu, Limonia acidissima, Pithecellobium dulce, Terminalia arjuna*, and *Terminalia elliptica* shows least density with 0.53±0.54 ha^{-1} each.

In the lower zone of Godavari River, *Borassus flabellifer* was the most abundant species (17.32±3.68 ha^{-1}) and it was followed by *Ficus racemosa* (8.15±2.08 ha^{-1}), *Barringtonia acutangula* (7.90±2.01 ha^{-1}) and *Eucalyptus grandis* (7.64±3.24 ha^{-1}). *Artocarpus heterophyllus, Bridelia retusa, Haldina cordifolia, Moringa oleifera, Peltophorum pterocarpum, Phyllanthus emblica, Prosopis juliflora* and *Spondias indica* were the least abundant species in the lower zone the Godavari River with 0.25±0.26 ha^{-1} (Table 5.3).

Table 5.3: Density of trees species in different zones and overall, in the Godavari River

Species	Upper Zone Density (ha^{-1})	Middle Zone Density (ha^{-1})	Lower Zone Density (ha^{-1})	Overall Density (ha^{-1})
Prosopis juliflora (Sw.) DC.	74.56 ± 6.58	40.34±8.67	0.25 ± 0.26	42.61±12.85
Borassus flabellifer L.	--	1.06±0.75	17.32 ± 3.68	6.28±3.44
Acacia nilotica (L.) Delile	9.18 ± 2.08	5.31±2.77	1.78 ± 0.75	5.92±2.11
Azadirachta indica A. Juss.	5.06 ± 1.14	4.25±1.61	5.35 ± 1.53	5.02±1.63
Ficus racemosa L.	0.94 ± 0.49	1.06±0.75	8.15 ± 2.08	3.50±1.31
Pongamia pinnata (L.) Pierre	4.31 ± 1.16	3.72±2.03	1.78 ± 0.84	3.32±1.40
Eucalyptus grandis W. Hill ex Maiden	0.56 ± 0.56	--	7.64 ± 3.24	2.96±1.69
Barringtonia acutangula (L.) Gaertn.	--	--	7.9 ± 2.01	2.78±1.45
Tectona grandis L.f.	1.31 ± 0.81	3.18±1.98	3.57 ± 1.71	2.42±1.20
Terminalia elliptica Willd.	1.69 ± 0.76	0.53±0.54	2.04 ± 1.39	1.61±0.86
Ziziphus mauritiana Lam.	1.87 ± 0.74	--	1.78 ± 0.98	1.53±0.60
Cordia myxa L.	0.75 ± 0.59	--	3.06 ± 1.23	1.44±0.68
Parkinsonia aculeata L.	3 ± 1.6	--	--	1.44±1.04
Pithecellobium dulce (Roxb.) Benth.	1.31 ± 0.86	0.53±0.54	1.78 ± 0.75	1.35±0.77
Butea monosperma (Lam.) Taub.	--	1.06±0.75	2.55 ± 1.43	1.08±0.59
Mallotus philippensis (Lam.) Müll.Arg.	--	--	3.06 ± 1.52	1.08±0.99
Acacia catechu (L.f.) Willd.	0.18 ± 0.19	0.53±0.54	2.29 ± 0.97	0.99±0.82
Balanites roxburghii Planch.	1.69 ± 0.93	--	--	0.81±0.81
Diospyros melanoxylon Roxb.	0.19 ± 0.19	--	2.04 ± 1.44	0.81±0.51
Cocos nucifera L.	--	--	2.04 ± 1.44	0.72±0.72
Ficus mollis Vahl	--	--	2.04 ± 0.87	0.72±0.38
Mangifera indica L.	1.12 ± 0.59	--	0.51 ± 0.51	0.72±0.49
Leucaena leucocephala (Lam.) de Wit	0.75 ± 0.59	--	0.76 ± 0.57	0.63±0.39
Tamarindus indica L.	0.94 ± 0.62	--	0.51 ± 0.36	0.63±0.32
Trewia nudiflora L.	--	--	1.78 ± 0.91	0.63±0.41
Cordia dichotoma G.Forst.	1.12 ± 0.65	--	--	0.54±0.46
Phoenix sylvestris (L.) Roxb.	--	2.65±1.76	--	0.45±0.45
Balanites glabra Mildbr. & Schltr.	0.75 ± 0.59	--	--	0.36±0.36
Bombax ceiba L.	0.37 ± 0.26	--	0.51 ± 0.36	0.36±0.22
Cordia sinensis Lam.	0.75 ± 0.59	--		0.36±0.28
Ficus hispida L.f.	0.75 ± 0.53	--		0.36±0.36
Putranjiva roxburghii Wall.	--	--	1.02 ± 0.62	0.36±0.36
Samanea saman (Jacq.) Merr.	0.75 ± 0.59	--		0.36±0.28
Syzygium cumini (L.) Skeels	0.19 ± 0.19	--	0.76 ± 0.44	0.36±0.22
Albizia lebbeck (L.) Benth.	0.56 ± 0.56	--		0.27±0.27
Holoptelea integrifolia (Roxb.) Planch.	--	--	0.76 ± 0.57	0.27±0.20

Species	Upper Zone Density (ha-¹)	Middle Zone Density (ha-¹)	Lower Zone Density (ha-¹)	Overall Density (ha-¹)
Moringa oleifera Lam.	0.37 ± 0.26	--	0.25 ± 0.26	0.27±0.15
Ailanthus excelsa Roxb.	0.37 ± 0.26	--	--	0.18±0.13
Albizia odoratissima (L.f.) Benth.	--	1.06±0.75	--	0.18±0.13
Dalbergia sissoo DC.	0.37 ± 0.26	--	--	0.18±0.13
Ficus religiosa L.	0.37 ± 0.26	--	--	0.18±0.13
Limonia acidissima Groff	0.19 ± 0.19	0.53±0.54	--	0.18±0.13
Mitragyna parvifolia (Roxb.) Korth.	--	--	0.51 ± 0.36	0.18±0.13
Sapindus mukorossi Gaertn.	--	--	0.51 ± 0.51	0.18±0.18
Senna siamea (Lam.) H.S.Irwin & Barneby	0.37 ± 0.26	--	--	0.18±0.18
Sterculia urens Roxb.	0.37 ± 0.26	--	--	0.18±0.18
Aegle marmelos (L.) Corrêa	0.19 ± 0.19	--	--	0.09±0.09
Annona reticulata L.	0.19 ± 0.19	--	--	0.09±0.09
Artocarpus heterophyllus Lam.	--	--	0.25 ± 0.26	0.09±0.09
Balanites aegyptiaca (L.) Delile	0.19 ± 0.19	--		0.09±0.09
Bridelia retusa (L.) A.Juss.	--	--	0.25 ± 0.26	0.09±0.09
Capparis divaricata Lam.	0.19 ± 0.19	--	--	0.09±0.09
Cassia javanica L.	0.19 ± 0.19	--	--	0.09±0.09
Cordia dentata Poir.	0.19 ± 0.19	--	--	0.09±0.09
Delonix regia (Bojer ex Hook.) Raf.	0.19 ± 0.19	--	--	0.09±0.09
Ficus benghalensis Roxb.	0.19 ± 0.19	--	--	0.09±0.09
Haldina cordifolia (Roxb.) Ridsdale	--	--	0.25 ± 0.26	0.09±0.09
Peltophorum pterocarpum (DC.) K.Heyne	--	--	0.25 ± 0.26	0.09±0.09
Phyllanthus emblica L.	--	--	0.25 ± 0.26	0.09±0.09
Sesbania sesban (L.) Merr.	0.19 ± 0.19	--	--	0.09±0.09
Spondias indica L.	--	--	0.25 ± 0.26	0.09±0.09
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	--	0.53±0.54	--	0.09±0.09
Terminalia pallida Brandis	0.19 ± 0.19	--	--	0.09±0.09
Vachellia farnesiana (L.) Wight & Arn.	0.19 ± 0.19	--	--	0.09±0.09
Total	**119.15±6.14**	**66.35±8.47**	**85.86±6.41**	**98.50±4.11**

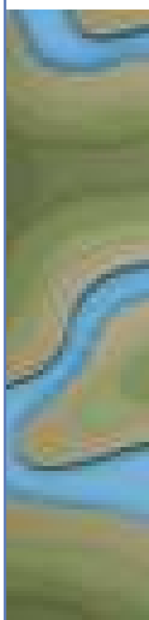
5.3.1.3 Importance Value Index (IVI) of tree

Importance Value Index (IVI) is the relative measure of density, dominance and occurrence of one species among the other species reported in a particular area. Analysis revealed *Prosopis juliflora* is the dominant species in the Godavari River (IVI: 86.80), followed by *Terminalia arjuna* (16.24), *Borassus flabellifer* (15.29), *Acacia nilotica* (13.27), and *Azadirachta indica* (11.29). The least dominant species in the Godavari River were *Haldina cordifolia* (0.39), *Capparis divaricate* (0.36), *Sesbania sesban* (0.30), *Bridelia retusa* (0.29), and *Ficus benghalensis* (0.27) (Table 5.4).

Prosopis juliflora was the dominant species in the upper and middle zone (125.52 and 122.98 respctively) of the Godavari River. In upper zone *Prosopis juliflora* was followed by *Acacia nilotica* (17.39), *Azadirachta indica* (10.42), and *Pongamia pinnata* (9.41). However, the middle zone was followed by *Terminalia arjuna* (43.77), *Albizia odoratissima* (26.03) and *Acacia nilotica* (18.52). In other hand the *Borassus flabellifer* was the most dominant species in lower zone (44.77) of the Godavari River. It was followed by *Mangifera indica* (24.62), *Ficus racemosa* (20.57), *Barringtonia acutangula* (20.32), and *Eucalyptus grandis* (18.06) (Table 5.4).

Table. 5.4 Importance value index (IVI) of dominant trees species in different zones and in the Godavari River

Species	Upper Zone	Middle Zone	Lower Zone	IVI Overall
Prosopis juliflora (Sw.) DC.	125.52	122.98	2.84	86.80
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	--	43.77	--	16.24
Borassus flabellifer L.	--	11.00	44.77	15.29
Acacia nilotica (L.) Delile	17.39	18.52	6.55	13.27
Azadirachta indica A.Juss.	10.42	14.63	14.27	11.29
Albizia odoratissima (L.f.) Benth.	--	26.03	--	9.06
Ficus racemosa L.	5.48	3.74	20.57	8.13
Pongamia pinnata (L.) Pierre	9.41	13.49	6.04	7.99
Barringtonia acutangula (L.) Gaertn.	--	--	20.32	6.75
Mangifera indica L.	6.82	--	24.62	6.6
Eucalyptus grandis W.Hill ex Maiden	9.40	--	18.06	6.33
Ficus mollis Vahl	--	--	13.20	6.3
Tectona grandis L.f.	3.27	12.60	9.07	5.55
Ficus religiosa L.	6.73	--	--	4.38
Cordia myxa L.	2.99	--	9.83	4.36
Pithecellobium dulce (Roxb.) Benth.	5.01	2.34	7.05	4.35
Terminalia elliptica Willd.	5.11	6.68	5.51	4.25
Acacia catechu (L.f.) Willd.	4.07	3.29	9.35	4.13
Samanea saman (Jacq.) Merr.	6.16	--	--	3.95
Ficus hispida L.f.	5.80	--	--	3.71
Ziziphus mauritiana Lam.	3.59	--	5.19	3.5
Albizia lebbeck (L.) Benth.	5.41	--	--	3.48
Delonix regia (Bojer ex Hook.) Raf.	5.32	--	--	3.47
Butea monosperma (Lam.) Taub.	--	4.34	8.29	3.35
Parkinsonia aculeata L.	5.33	--	--	3.11
Syzygium cumini (L.) Skeels	6.19	--	5.01	3.01
Cocos nucifera L.	--	--	7.40	2.98
Tamarindus indica L.	2.01	--	16.81	2.81
Dalbergia sissoo DC.	4.28	--	--	2.77
Mallotus philippensis (Lam.) Müll.Arg.	--	--	8.00	2.69
Cordia dichotoma G.Forst.	4.14	--	--	2.57
Senna siamea (Lam.) H.S.Irwin & Barneby	3.44	--	--	2.22
Phoenix sylvestris (L.) Roxb.	--	11.15	--	2.11
Leucaena leucocephala (Lam.) de Wit	4.15	--	1.92	2.1
Balanites roxburghii Planch.	3.41	--	--	2.02
Limonia acidissima Groff	3.13	5.44	--	2.02
Cassia javanica L.	2.95	--	--	1.91
Trewia nudiflora L.	--	--	5.16	1.85



Species	Upper Zone	Middle Zone	Lower Zone	IVI Overall
Diospyros melanoxylon Roxb.	0.93	--	4.97	1.79
Bombax ceiba L.	0.69	--	6.93	1.75
Terminalia pallida Brandis	2.54	--	--	1.65
Balanites glabra Mildbr. & Schltr.	2.63	--	--	1.63
Cordia sinensis Lam.	2.42	--	--	1.49
Holoptelea integrifolia (Roxb.) Planch.	--	--	3.30	1.42
Sterculia urens Roxb.	2.14	--		1.36
Putranjiva roxburghii Wall.	--	--	3.40	1.32
Cordia dentata Poir.	2.02	--	--	1.3
Vachellia farnesiana (L.) Wight & Arn.	1.37	--	--	0.88
Mitragyna parvifolia (Roxb.) Korth.	--	--	1.91	0.78
Sapindus mukorossi Gaertn.	--	--	1.91	0.78
Moringa oleifera Lam.	0.91	--	1.00	0.75
Ailanthus excelsa Roxb.	2.99	--	--	0.73
Aegle marmelos (L.) Corrêa	1.12	--	--	0.71
Annona reticulata L.	1.05	--	--	0.67
Artocarpus heterophyllus Lam.	--	--	1.40	0.65
Phyllanthus emblica L.	--	--	1.40	0.65
Spondias indica Willd.	--	--	1.17	0.51
Balanites aegyptiaca (L.) Delile	0.72	--	--	0.45
Peltophorum pterocarpum (DC.) K.Heyne	--	--	1.05	0.42
Haldina cordifolia (Roxb.) Ridsdale	-	--	0.95	0.39
Capparis divaricata Lam.	0.59	--	--	0.36
Sesbania sesban (L.) Merr.	0.50	--	--	0.3
Bridelia retusa (L.) A.Juss.	--	--	0.79	0.29
Ficus benghalensis Roxb.	0.45	--	--	0.27
Total	**300**	**300**	**300**	**300**

5.3.1.4 Above Ground Biomass (AGB) and Carbon stock

Above Ground Biomass is an important variable for evaluating carbon sequestration and carbon balance capacity of forest ecosystems. Accurate estimation of forest biomass is particularly important for studying the carbon cycle of the terrestrial ecosystem in large areas (Lu et al., 2005, and Li et al., 2015). The estimated value of above-ground biomass and carbon stock indicated that these habitat supports valuable carbon stock which is vital in mitigating climate change through carbon sequestration. The overall above ground biomass was 6.98±0.53 Mg ha^{-1}. Lower zone showcased a substantial amount of above-ground biomass (10.67±1.62 Mg ha^{-1}), followed by upper zone and middle zone (Table 5.5).

Table 5.5: Distribution of AGB and Carbon stock (Mg ha^{-1}) in different zones of Godavari River

Zone	AGB (Mg ha^{-1})	(Mg C ha^{-1})
Upper	8.93±0.84	4.47±0.42
Middle	6.37±1.4	3.19±0.7
Lower	10.67±1.62	5.33±0.81
Overall	**6.98±0.53**	**3.49±0.27**

5.3.2 Shrubs

A total of 20 species of shrubs belonging to 12 families and 19 genera were recorded in the Godavari River. The diversity of shrubs in the Godavari River was low (*H'*=2.08). Family Fabaceae supports the highest number of species (n= 4), followed by Solanaceae, and Euphorbiaceae, (n= 3 species each) (Figure 5.9). Eight families viz., Apocynaceae, Capparaceae, Convolvulaceae, Lythraceae, Malvaceae, Phyllanthaceae, Rhamnaceae, and Verbenaceae were represented by only one species each. A total 18 species (90%) of the shrubs were perennial in nature and only two species *Datura metel* and *Ipomoea carnea* was annual. Five exotic species viz., *Indigofera tinctoria, Ipomoea carnea, Jatropha curcas, Lantana camara*, and *Solanum torvum* were recorded in the Godavari River. Information on the shrubs recorded in the Godavari River are given in Appendix 5.3.

Richness of the shrubs was comparatively high in the upper zone (n=18 species) than lower zone (n=9 species) and middle zone (n=8 species). However, all three zones of the Godavari River sustain low diversity of the shrubs (Table 5.6). In the upper zone, Solanaceae and Euphorbiaceae was the most represented family. Fabaceae Family was the most common in lower zone with three species *viz., Senna auriculata, Alantsilodendron pilosum*, and *Guilandina bonduc*. Apocynaceae, Capparaceae, Convolvulaceae, Lythraceae, Malvaceae, Phyllanthaceae, Rhamnaceae, Verbenaceae, Lamiaceae, Euphorbiaceae, and Solanaceae were represented by single species in the lower zone of the Godavari River, while the upper zone had five exotic species, *Indigofera tinctoria, Ipomoea carnea, Jatropha curcas, Lantana camara* and *Solanum torvum*. However, the middle and lower zone were represented only by *Lantana camara*. Among the all three zones of river, only one species *Indigofera tinctoria, Jatropha curcas, Lantana camara* and *Solanum torvum* was perennial in the nature. Table 5.6 provides the information on the shrubs recorded in the Godavari River.

Table 5.6 Summary of shrub species found in Godavari River

Parameter	Shrub			
	Upper Zone	Middle Zone	Lower Zone	Over all
Species	18	8	9	20
Family	11	7	8	12
Order	10	5	7	11
Genus	17	8	9	19
Diversity (Shannon's *H'*)	1.12	1.63	1.71	2.08
Near Threatened (NT)	0	0	0	0
Data deficient (DD)	0	0	0	0
Not Evaluated (NE)	11	3	6	12
Least concern (LC)	7	5	3	8
Vulnerable (VU)	0	0	0	0
Native	15	7	8	15
Exotic	5	1	1	5
Annual	2	0	1	2
Perennial	16	8	8	18

5.3.2.1 Richness and diversity of the shrubs in various segments

Maximum richness of shrubs species was observed in segment 2 (n= 9 species) followed by segment 1, 7 and segment 21. High diversity of shrubs was observed at segment 2 (*H'*= 1.76) followed by segment 7 (*H'*= 1.64). Segment 14 (*H'*= 0.27) supported the lowest diversity of the shrubs. Figure 5.8 highlight the richness and diversity of shrubs at various sampling segments.

Figure 5.8
Richness and diversity of shrubs at various segments in Godavari River

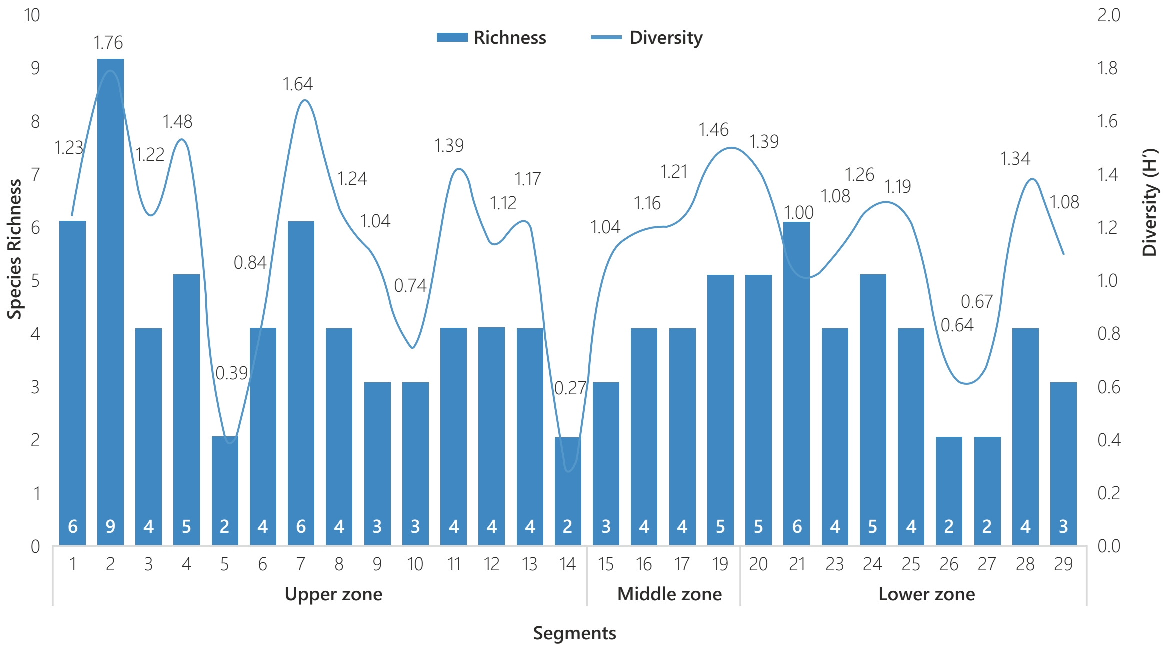
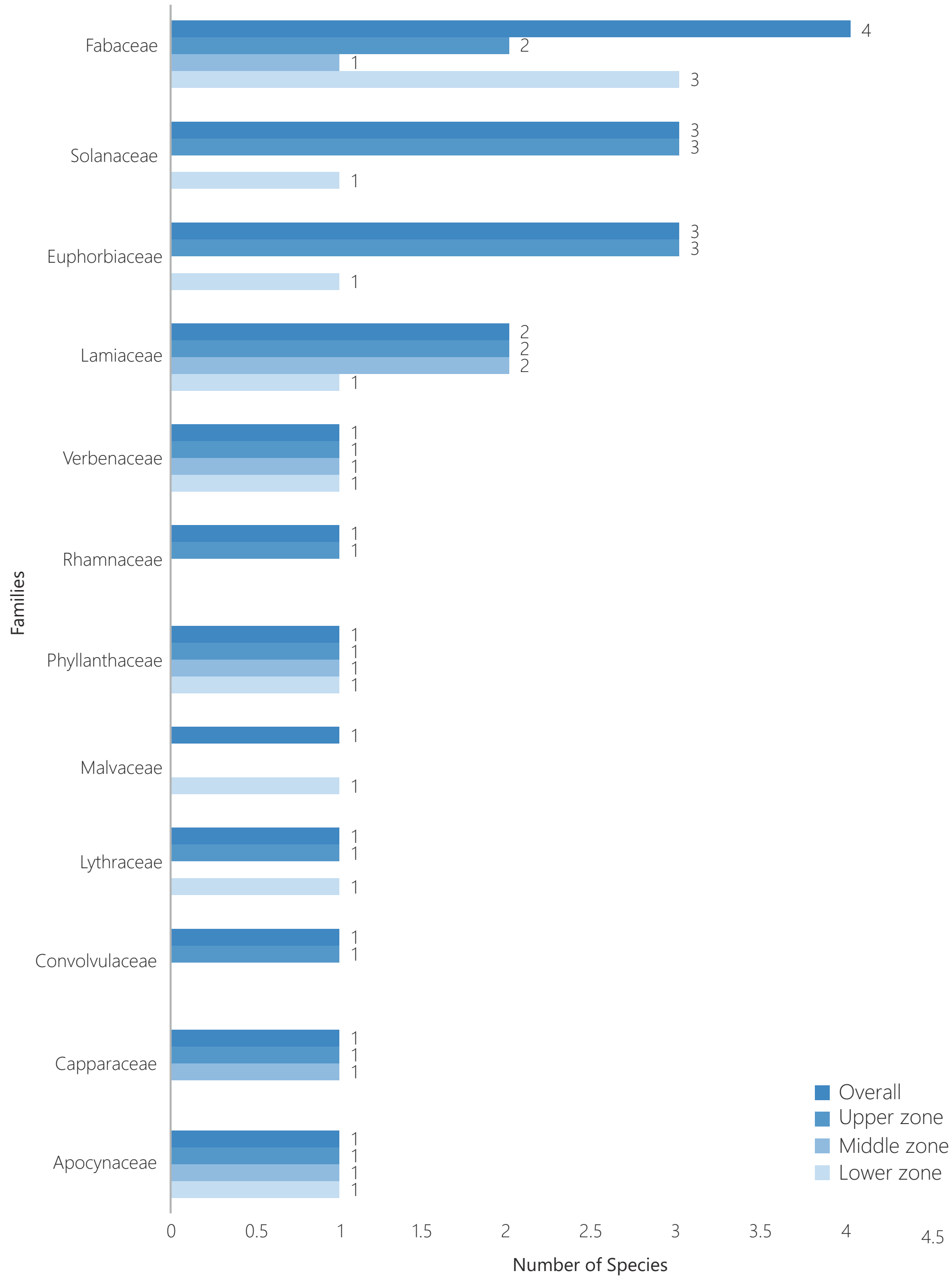
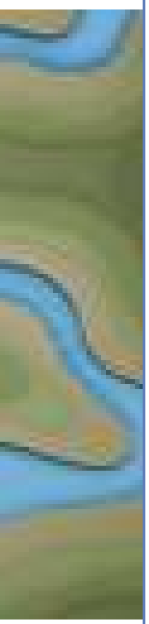


Figure 5.9
Families of shrub with their number of species in different zones of the Godavari River





5.3.2.2 Abundance of the shrubs in various segments

The average density of shrubs in the Godavari River was 88.88±5.29 ha^{-1}. The invasive species *Lantana camara* (99.92±26.73 ha^{-1}) is the most abundant shrub species in the river, followed by *Phyllanthus reticulatus* (67.95±17.51 ha^{-1}), *Vitex negundo* (57.96±18.33 ha^{-1}) *Datura metel* (40.97±22.08 ha^{-1}), and *Calotropis procera* (23.98±7.63 ha^{-1}). *Alantsilodendron pilosum, Guilandina bonduc, Helicteres isora, Indigofera tinctoria*, and *Jatropha curcas* were with least density of 1.00±1.00 ha^{-1} for each in the Godavari River.

The upper zone of the river support higher shrub density (94.72±7.89 ha^{-1}) than the middle zone (78.12±12.45 ha^{-1}) and lower zone (86.29±8.72 ha^{-1}). While *Lantana camara* recorded the highest density in the upper zone (156.06±50.34 ha^{-1}) and middle zone (113.91±61.93 ha^{-1}). *Vitex negundo* was the most abundant (116.96±45.24 ha^{-1}) species in lower zone of the Godavari River (Table 5.7). Zone wise density of various shrub species of the Godavari River is provided in Table 5.7.

Table 5.7 Density of various shrub species recorded in various zone of the Godavari River

Species	Upper Zone Density (ha^{-1})	Middle Zone (ha^{-1})	Lower Zone (ha^{-1})	Overall Density (ha^{-1})
Lantana camara L.	156.06±50.34	113.91±61.93	116.96±45.24	99.92±26.73
Phyllanthus reticulatus Poir.	70.75±44.62	71.95±51.15	102.70±39.85	67.95±17.51
Vitex negundo L.	43.70±16.75	65.95±41.43	57.96±18.33	57.96±18.33
Datura metel L.	40.97±22.08	31.21±13.15	19.97±15.32	40.97±22.08
Calotropis procera (Aiton) W.T. Aiton	23.98±7.63	31.21±13.15	22.82±11.98	23.98±7.63
Woodfordia fruticosa (L.) Kurz	17.99±14.10	48.50±40.17	48.50±40.17	17.99±14.10
Senna auriculata (L.) Roxb.	13.99±5.95	35.97±26.63	8.56±4.90	13.99±5.95
Capparis sepiaria L.	10.40±6.21	11.99±11.99	6.99±3.58	6.99±3.58
Solanum torvum Sw.	8.32±4.12	-	-	14.00±1.95
Clerodendrum phlomidis L.f.	2.00±1.41	2.08±2.08	-	2.00±1.41
Ipomoea carnea Jacq.	4.16±2.93	-	-	2.00±1.41
Jatropha gossypiifolia L.	6.00±6.00	6.00±6.00	-	2.00±1.41
Ricinus communis L.	4.16±2.93	-	-	2.00±1.41
Withania somnifera (L.) Dunal	4.16±2.93	-	-	2.00±1.41
Ziziphus nummularia (Burm.f.) Wight & Arn.	4.16±2.93	-	-	2.00±1.41
Alantsilodendron pilosum (Vahl) J.H.Kirkbr.	-	-	2.85±2.85	1.00±1.00
Guilandina bonduc L.	-	-	2.85±2.85	1.00±1.00
Helicteres isora L.	-	-	2.85±2.85	1.00±1.00
Indigofera tinctoria L.	-	-	2.08±2.08	1.00±1.00
Jatropha curcas L.	2.08±2.08	-	-	1.00±1.00
Total	**94.72±7.89**	**78.12±12.45**	**86.29±8.72**	**88.88±5.29**

5.3.3 Herbs

A total of 101 species of herbs belonging to 30 families and 84 genera were recorded along the Godavari River. Maximum number of species belong to the family Asteraceae (n=19 species) followed by Amaranthaceae (n=11 species) and Fabaceae (n=10 species). Fourteen families of herbs were represented by only one species each (Figure 5.10).

The majority of herbs found in the basin were annual (n=59 species) and remaining were perennial (n=42 species) in nature. Of the recorded species of herbs in the Godavari River 37 species were exotic (Table 5.8). The highest number of annual species of herbs are recorded in the upper zone (n=49 species) and lowest was in the middle zone (n=25 species). The details of the herb's species recorded in the Godavari River during the survey are presented in Appendix 5.4.

The upper zone of the Godavari River supported high richness of herbs (n=85 species). A total of 54 species of herbs was recorded in the lower zone, and 38 species in the middle zone belonging to, 21 and 14 families respectively. In all three zones, family Asteraceae was the dominant followed by Amaranthaceae, and Fabaceae (Figure 5.12). Upper zone supported higher number of exotics (33 species) and perennial species (36 species) of herbs.

Table 5.8 Summary of herb species found in Godavari River

Parameter	Herbs			
	Upper Zone	Middle Zone	Lower Zone	Over all
Species	85	38	54	101
Family	27	14	21	30
Order	14	12	03	16
Genus	71	34	47	84
Diversity (Shannon's H')	2.88	2.97	3.22	3.28
Near Threatened (NT)	0	0	0	0
Data Deficient (DD)	0	0	0	0
Not Evaluated (NE)	65	31	43	77
Least Concern (LC)	20	7	11	24
Vulnerable (VU)	0	0	0	0
Exotic	33	12	14	37
Native	52	26	40	64
Annual	49	25	38	59
Perennial	36	13	16	42

5.3.3.1 Richness and diversity of the Herbs in various segments

Maximum richness of herbs was observed at segment 26 (n=31 species) followed by segment 23, and segment 2 with 29 and 28 species respectively. Lowest richness was observed at segment 6. High diversity of herb was observed at segment 19 (H'= 2.97) followed by segment 26 (H'= 2.96). Segment 5 (H'= 1.54) supported the lowest diversity of the herb. Figure 5.11 highlight the richness and diversity of herbs at various sampling segments.

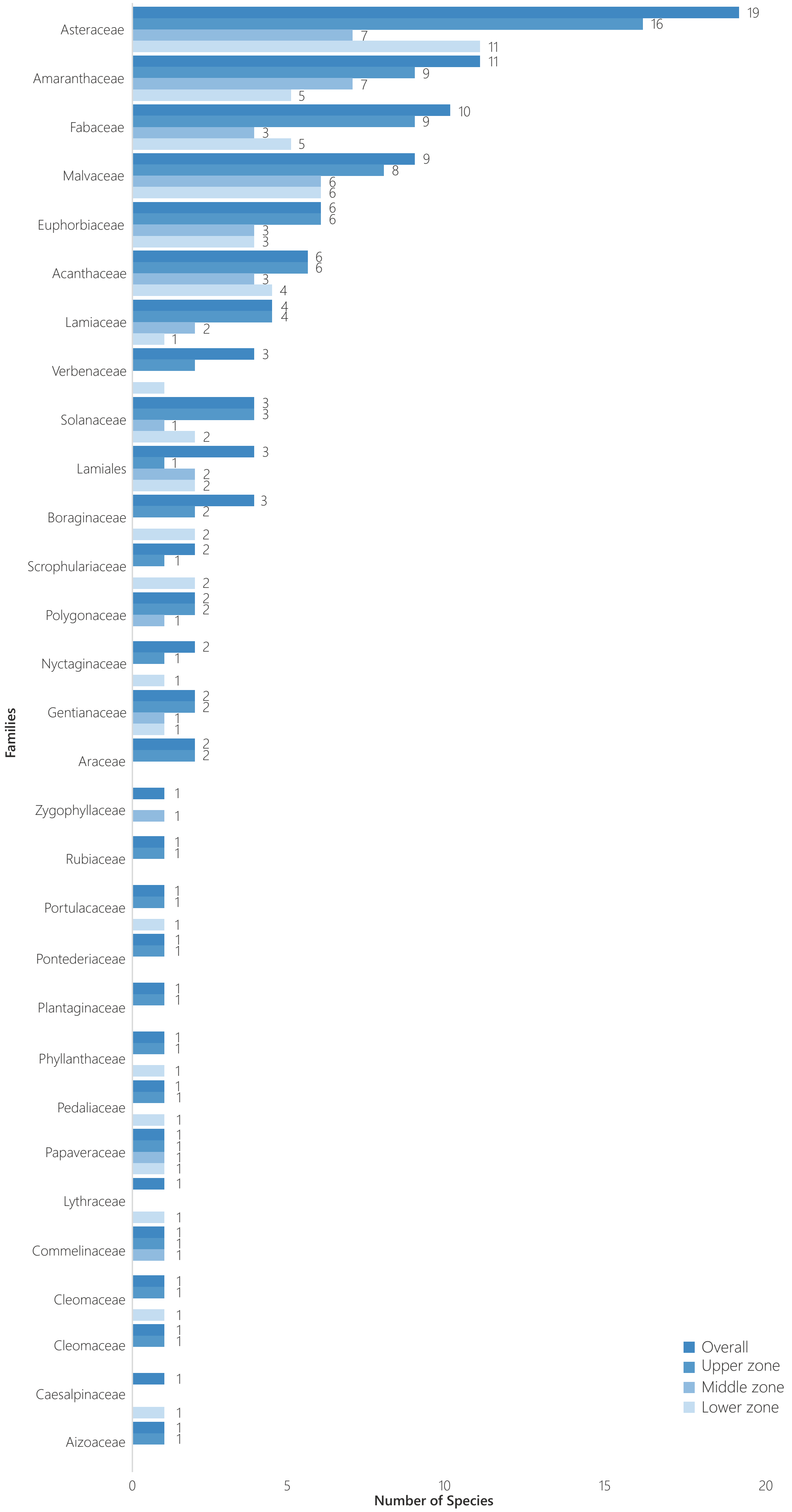
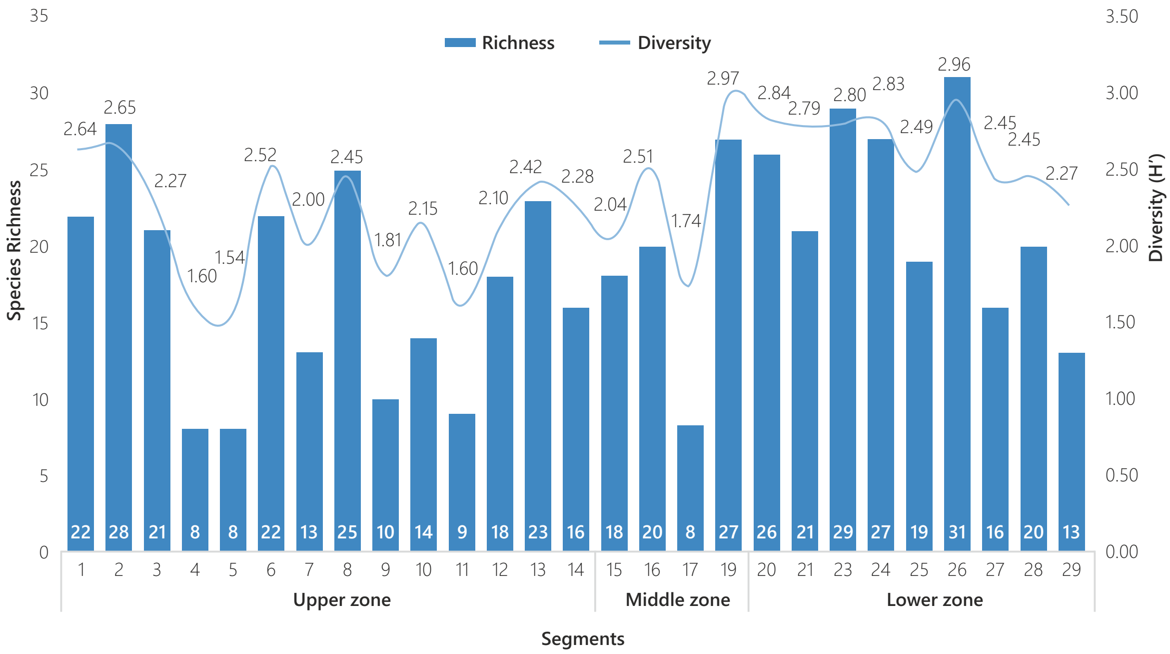


Figure 5.10 Number of species recorded in various families of herbs in Godavari River

Figure 5.11 Richness and diversity of herbs at various sampling sites in Godavari River



5.3.3.2 Abundance of Herbs

Alternanthera sessilis was the most abundant (1791.83±43.52 ha^{-1}) herb species in the river followed by *Parthenium hysterophorus* (950.63±38.92 ha^{-1}), *Chromolaena odorata* (389.83±27.88 ha^{-1}) and *Xanthium strumarium* (332.83±26.22 ha^{-1}) (Table 5.9). On the contrary, herb species with lowest density in the Godavari River was *Acalypha indica, Boerhavia erecta, Canscora diffusa, Erigeron acris, Erigeron trilobus, Laggera crispate, Launaea nudicaulis, Mitracarpus hirtus, Orthosiphon parvifolius, Pistia stratiotes, Pontederia crassipes, Pulicaria Arabica, Trianthema portulacastrum*, *Verbascum chinense, Verbena supine*, and *Vicia monantha* with 2.28±2.27 ha^{-1} each.

Alternanthera sessilis recorded highest density in all the three zones of the of the Godavari River. In the upper zone, dominant species *Alternanthera sessilis* (2409.01±56.10 ha^{-1}) was followed by *Parthenium hysterophorus* (1199.69±59.98 ha^{-1}), *Malvastrum coromandelianum* (342.08±38.33 ha^{-1}) and *Peristrophe paniculata* (337.26±38.69 ha^{-1}). In the middle zone, *Alternanthera sessilis* (1088.11±102.77 ha^{-1}) was followed by *Mesosphaerum suaveolens* (597.13±80.24 ha^{-1}) *Parthenium hysterophorus* (597.13±80.24 ha^{-1}), and *Achyranthes aspera* (517.52±75.84 ha^{-1}). In the lower zone dominant species *Alternanthera sessilis* (1309.84±70.95 ha^{-1}) was followed by *Chromolaena odorata* (969.54±65.80 ha^{-1}), *Parthenium hysterophorus* (789.76±61.75 ha^{-1}), *Blumea eriantha* (577.87±55.11 ha^{-1}) and *Xanthium strumarium* (571.45±54.87 ha^{-1}). Density of abundant herbs species in the Godavari River is provided in the Table 5.9.

Table.5.9 Density of herb in different zones in the Godavari River

Species	Upper Zone Density (ha^{-1})	Middle Zone Density (ha^{-1})	Lower Zone Density (ha^{-1})	Overall Density (ha^{-1})
Alternanthera sessilis (L.) R.Br. ex DC.	2409.01±56.10	1088.11±102.77	1309.84±70.95	1791.83±43.52
Parthenium hysterophorus L.	1199.69±59.98	597.13±80.24	789.76±61.75	950.63±38.92
Chromolaena odorata (L.) R.M.King & H.Rob.	77.09±19.02	53.08±26.32	969.54±65.80	389.83±27.88
Xanthium strumarium L.	236.08±33.13	106.16±36.90	571.45±54.87	332.83±26.22
Achyranthes aspera L.	255.36±34.30	517.52±75.84	333.88±43.81	328.27±26.06
Solanum virginianum L.	91.54±20.68	238.85±54.15	552.19±54.89	280.40±24.32
Mesosphaerum suaveolens (L.) Kuntze	187.90±29.17	597.13±80.24	134.84±28.79	239.37±22.42
Blumea eriantha DC.	--	106.16±41.40	577.87±55.11	223.41±21.96
Peristrophe paniculata (Forssk.) Brummitt	337.26±38.69	252.12±55.50	32.10±14.28	214.29±21.55
Malvastrum coromandelianum (L.) Garcke	342.08±38.33	199.04±49.76	--	196.05±20.44
Argemone mexicana L.	202.36±30.19	39.81±22.84	231.15±37.10	184.65±19.88
Cyanthillium cinereum (L.) H.Rob.	149.36±26.17	212.31±51.28	179.78±33.00	170.98±19.17
Senna tora (L.) Roxb.	255.36±33.61	66.35±29.36	83.47±22.85	161.86±18.68
Lippia alba (Mill.) N.E.Br.	--	--	378.83±46.29	134.50±17.11
Croton bonplandianus Baill.	149.36±26.17	13.27±13.24	154.10±30.68	127.66±16.68
Sphaeranthus indicus L.	--	66.35±29.36	314.62±42.67	123.10±16.40
Rungia pectinata (L.) Nees	139.72±25.35	53.08±26.32	77.05±21.97	102.59±15.02
Abutilon grandifolium (Willd.) Sweet	91.54±20.68	199.04±49.76	44.95±16.87	93.47±14.36
Abutilon indicum (L.) Sweet	81.91±19.59	199.04±49.76	25.68±12.79	82.07±13.48
Aerva lanata (L.) Juss. ex Schult.	--	106.16±36.90	179.78±33.00	82.07±13.48
Ageratum conyzoides L.	24.09±10.72	119.43±39.06	134.84±28.79	79.79±13.29
Chrozophora rottleri (Geiseler) A.Juss. ex Spreng.	33.73±12.67	13.27±13.24	154.10±30.68	72.95±12.72
Sida cordifolia L.	33.73±12.67	66.35±29.36	122.00±28.91	70.67±12.94
Tephrosia purpurea (L.) Pers.	81.91±19.59	53.08±26.32	44.95±16.87	63.83±11.92
Ammannia baccifera L.	--	--	173.36±33.69	61.55±12.14
Celosia argentea L.	9.64±6.80	66.35±29.36	122.00±27.45	59.27±11.49
Heliotropium europaeum L.	--	--	166.94±31.87	59.27±11.49
Sida acuta Burm.f.	48.18±15.11	132.70±41.08	38.52±15.63	59.27±11.49
Acmella paniculata (Wall. ex DC.) R.K.Jansen	48.18±15.11	--	77.05±21.97	50.15±10.59
Coldenia procumbens L.	4.82±4.81	--	134.84±28.79	50.15±10.59
Digera muricata (L.) Mart.	4.82±4.81	13.27±13.24	109.15±26.02	43.31±9.85
Hygrophila auriculata (Schumach.) Heine	86.72±20.15	--	--	41.03±9.59
Euphorbia hirta L.	24.09±10.72	39.81±22.84	51.37±18.01	36.47±9.05
Ocimum basilicum L.	--	--	102.73±25.27	36.47±9.05
Ocimum tenuiflorum L.	28.91±11.74	79.62±32.10	25.68±12.79	36.47±9.05
Tridax procumbens L.	38.54±13.53	--	51.37±18.01	36.47±9.05
Hemigraphis latebrosa (Buch.-Ham. ex D.Don) Bennet	4.82±4.81	13.27±13.24	77.05±21.97	31.92±8.47

Species	Upper Zone Density (ha^{-1})	Middle Zone Density (ha^{-1})	Lower Zone Density (ha^{-1})	Overall Density (ha^{-1})
Solanum nigrum L.	38.54±13.53	--	32.10±14.28	29.64±8.17
Euploca ovalifolia (Forssk.) Diane & Hilger	57.82±16.53	--	--	27.36±7.85
Vicoa indica (L.) DC.	24.09±10.72	--	44.95±16.87	27.36±7.85
Persicaria glabra (Willd.) M.Gómez	38.54±13.53	39.81±22.84	--	25.08±7.52
Commelina benghalensis L.	38.54±13.53	26.54±18.69	--	22.80±7.17
Psoralea corylifolia L.	14.45±8.32	26.54±18.69	32.10±14.28	22.80±7.17
Urena lobata L.	48.18±15.11	--	--	22.80±7.17
Alternanthera philoxeroides (Mart.) Griseb.	38.54±13.53	13.27±13.24	--	20.52±6.80
Cleome viscosa L.	19.27±9.60	--	32.10±14.28	20.52±6.80
Senna occidentalis (L.) Link	--	--	57.79±19.09	20.52±6.80
Phyla nodiflora (L.) Greene	38.54±13.53	--	--	18.24±6.42
Phyllanthus niruri L.	14.45±8.32	--	32.10±14.28	18.24±6.42
Amaranthus viridis L.	28.91±11.74	13.27±13.24	--	15.96±6.01
Flemingia strobilifera (L.) W.T.Aiton	28.91±11.74	--	6.42±6.41	15.96±6.01
Ocimum africanum Lour.	--	92.89±34.59	--	15.96±6.01
Solanum chenopodioides Lam.	33.73±12.67	--	--	15.96±6.01
Chrozophora tinctoria (L.) A.Juss.	24.09±10.72	--	--	11.40±5.08
Dipteracanthus prostratus (Poir.) Nees	--	26.54±18.69	19.26±11.09	11.40±5.08
Grangea maderaspatana (L.) Poir.	--	--	32.10±14.28	11.40±5.08
Ruellia prostrata Poir.	4.82±4.81	--	25.68±12.79	11.40±5.08
Senna obtusifolia (L.) H.S.Irwin & Barneby	24.09±10.72	--	--	11.40±5.08
Sida rhombifolia L.	4.82±4.81	26.54±18.69	12.84±9.06	11.40±5.08
Acmella radicans (Jacq.) R.K.Jansen	19.27±9.60	--	--	9.12±4.54
Alternanthera paronychioides A.St.-Hil.	19.27±9.60	--	--	9.12±4.54
Chenopodium album L.	19.27±9.60	--	--	9.12±4.54
Melilotus albus Medik.	--	--	25.68±12.79	9.12±4.54
Portulaca oleracea L.	9.64±6.80	--	12.84±9.06	9.12±4.54
Amaranthus spinosus L.	14.45±8.32	--	--	6.84±3.94
Boerhaavia diffusa L.	4.82±4.81	--	19.26±11.09	6.84±3.94
Cleome chelidonii L.f.	14.45±8.32	--	--	6.84±3.94
Cosmos caudatus Kunth	14.45±8.32	--	--	6.84±3.94
Ecbolium ligustrinum (Vahl) Vollesen	14.45±8.32	--	--	6.84±3.94
Leonotis nepetifolia (L.) R.Br.	9.64±6.80	13.27±13.24	--	6.84±3.94
Azanza lampas (Cav.) Alef.	--	--	12.84±9.06	4.56±3.22
Bacopa monnieri (L.) Wettst.	9.64±6.80	--	--	4.56±3.22
Colocasia esculenta (L.) Schott	9.64±6.80	--	--	4.56±3.22
Cyathocline purpurea (Buch.-Ham. ex D.Don) Kuntze	4.82±4.81	--	6.42±6.41	4.56±3.22

Species	Upper Zone Density (ha^{-1})	Middle Zone Density (ha^{-1})	Lower Zone Density (ha^{-1})	Overall Density (ha^{-1})
Deeringia spicata (Roxb.) W.Wight	9.64±6.80	--	--	4.56±3.22
Desmanthus virgatus (L.) Willd.	9.64±6.80	--	--	4.56±3.22
Euphorbia serpens Kunth	9.64±6.80	--	--	4.56±3.22
Hibiscus flabifolius	9.64±6.80	--	--	4.56±3.22
Nicoteba betonica (L.) G. Don	9.64±9.62	--	--	4.56±4.55
Phaseolus vulgaris L.	9.64±6.80	--	--	4.56±3.22
Rumex palustris Sm.	9.64±6.80		--	4.56±3.22
Sesamum indicum L.	4.82±4.81		6.42±6.41	4.56±3.22
Sonchus oleraceus L.	9.64±6.80		--	4.56±3.22
Trifolium campestre Schreb.	9.64±6.80	26.54±18.69	--	4.56±3.22
Tribulus terrestris L.	--	26.54±18.69	--	4.56±3.22
Acalypha indica L.	4.82±4.81	--	--	2.28±2.27
Boerhavia erecta L.	4.02±4.01	--	--	2.28±2.27
Canscora diffusa (Vahl) R.Br. ex Roem. & Schult.	4.82±4.81	--	--	2.28±2.27
Erigeron acris L.	4.82±4.81	--	--	2.28±2.27
Erigeron trilobus (Desf.) Boiss.	4.82±4.81	--	--	2.28±2.27
Laggera crispata (Vahl) Hepper & Wood	4.82±4.81	--	--	2.28±2.27
Launaea nudicaulis (L.) Hook.f.	4.82±4.81	--	--	2.28±2.27
Mitracarpus hirtus (L.) DC.	4.82±4.81	--	--	2.28±2.27
Orthosiphon parvifolius (Roxb.) Benth.	4.82±4.81	--	--	2.28±2.27
Pistia stratiotes L.	4.82±4.81	--	--	2.28±2.27
Pontederia crassipes Mart.	4.82±4.81	--	--	2.28±2.27
Pulicaria arabica (L.) Cass.	4.82±4.81	--	--	2.28±2.27
Trianthema portulacastrum L.	4.82±4.81	--	--	2.28±2.27
Verbascum chinense (L.) Santapau	--	--	6.42±6.41	2.28±2.27
Verbena supina L.	4.82±4.81	--	--	2.28±2.27
Vicia monantha Retz.	4.82±4.81	--	--	2.28±2.27
Total	**7520.93±142.70**	**5613.05±304.18**	**8944.16±200.47**	**7698.48±115.13**

5.3.4 Grasses

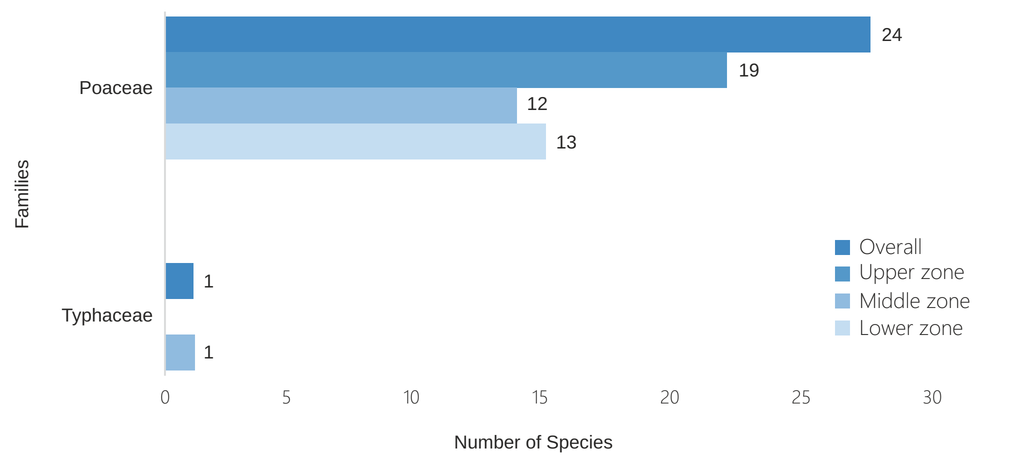
A total of 25 species of grass belonging to 12 genera and two families were recorded in the Godavari River (Table 5.10). Highest number of species belong to the family Poaceae (n=19 species), followed by Typhaceae (n=1 Species). Family Typhaceae was represented by single species (Figure 5.12). Of the recorded grasses 23 species (92%) are native and only 2 species (8%) is exotic viz., *Digitaria ciliaris* and *Setaria verticillata*.

Most of the grasses were perennial (n=17 species) and only eight species of grass were annual in nature. Data of grass species recorded in the Godavari River are presented in Table 5.10. The upper zone of the Godavari River harbour the highest number of grass species (n=19 species). The upper zone and lower zone equally supported the higher number of annual species (n=6 species) (Table 5.10). The details of the grass species recorded in the Godavari River during the survey are presented in Appendix 5.5

Table 5.10 Summary of grass species found in Godavari River

Parameter	Grasses			
	Upper Zone	Middle Zone	Lower Zone	Over all
Species	19	12	14	25
Family	1	2	1	2
Order	1	1	1	1
Genus	19	12	14	12
Diversity (Shannon's *H'*)	2.06	1.90	1.59	2.03
Near Threatened (NT)	0	0	0	0
Data Deficient (DD)	0	0	0	0
Not Evaluated (NE)	14	7	8	16
Least Concern (LC)	5	5	6	9
Vulnerable (VU)	0	0	0	0
Native	17	11	14	23
Exotic	2	1	0	2
Annual	6	4	6	8
Perennial	13	8	8	17

Figure 5.12 Number of species recorded in various families of grasses in Godavari River



5.3.4.1 Richness and diversity of Grasses in various segments

Maximum richness of grass species observed at segment 19 (n=10 species) and it was followed segment 12 and segment 16. The lowest richness was observed at segment 7 and 10 (n=3 species each). The Highest diversity of grass was also recorded at segment 19 (H'=1.93). Segment 7 and 10 supported lowest diversity of grass species. Figure 5.13 highlight the richness and diversity of grass at various sampling segments.

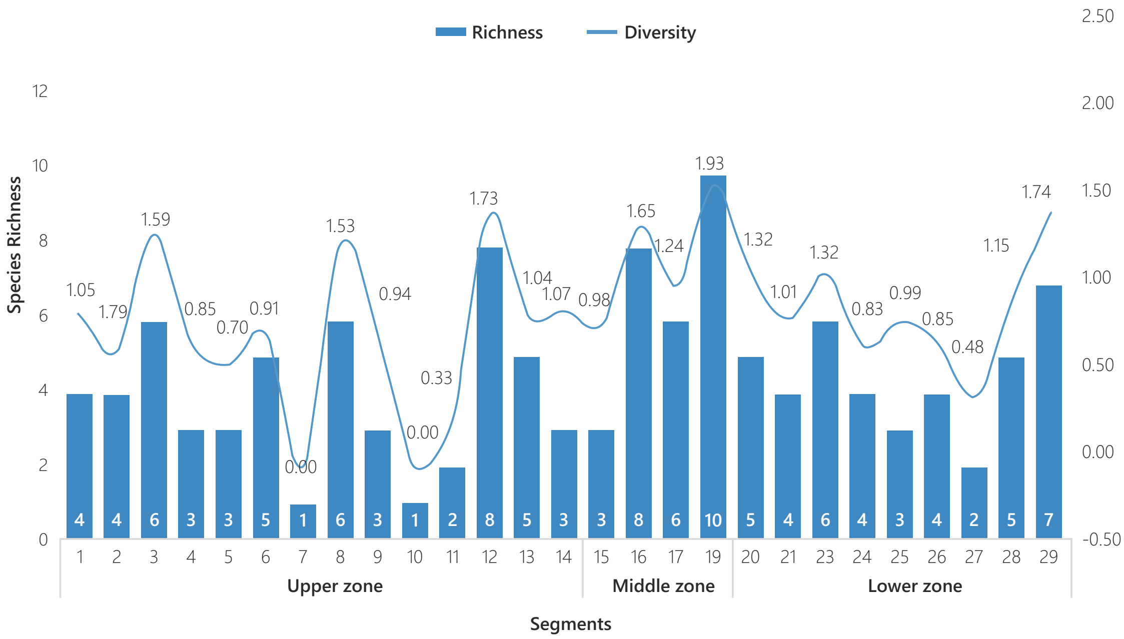


Figure 5.13 Richness and diversity of Grasses at various sampling sites in Godavari River

5.3.4.2 Abundance of Grasses

Cynodon dactylon with 747.74±36.76 ha^{-1} was dominating grass species recorded in the Godavari River followed by *Dichanthium annulatum* (724.94±36.10 ha^{-1}), *Apluda mutica* (164.14±18.81 ha^{-1}), *Eragrostis tenella* and *Saccharum spontaneum* with 116.26±15.95 ha^{-1}.

Among all three zones of the Godavari River, the upper zone and lower zone were dominated by *Cynodon dactylon*, followed by *Dichanthium annulatum*. The middle zone of the River, was dominated by *Dichanthium annulatum* (1207.54±99.74 ha^{-1}) followed by *Apluda mutica* and *Cynodon dactylon* (477.71±73.40 ha^{-1} each). The Lower zone of the river was also dominated by *Cynodon dactylon* with 1155.74±70.53 ha^{-1}. Table 5.11 provides density of various grass species reported in various zone of the Godavari River.

Table.5.11 Density of grass species recorded in different zones of the Godavari River

Species	Upper zone Density (ha^{-1})	Middle zone Density (ha^{-1})	Lower zone Density (ha^{-1})	Overall Density (ha^{-1})
Cynodon dactylon (L.) Pers.	539.62±47.42	477.71±73.40	1155.74±70.53	747.74±36.76
Dichanthium annulatum (Forssk.) Stapf	337.26±38.09	1207.54±99.74	1008.06±68.35	724.94±36.10
Apluda mutica L.	158.99±26.96	477.71±73.40	19.26±11.09	164.14±18.81
Eragrostis tenella (L.) P.Beauv. ex Roem. & Schult.	--	145.97±42.99	256.83±38.94	116.26±15.95
Saccharum spontaneum L.	--	358.28±64.96	154.10±30.68	116.26±15.95
Chloris virgata Sw.	125.27±24.06	212.31±51.28	12.84±9.06	100.31±14.86
Themeda triandra Forssk.	144.54±25.76	13.27±13.24	--	70.67±12.53
Dactyloctenium aegyptium (L.) Willd.	24.09±12.70	66.35±29.36	83.47±22.85	52.43±11.29
Echinochloa colona (L.) Link	43.36±14.34	26.54±18.69	51.37±18.01	43.31±9.85
Setaria verticillata (L.) P.Beauv.	48.18±15.11	92.89±34.59	--	38.75±9.33
Cenchrus ciliaris L.	72.27±18.43	--	--	34.20±8.77
Saccharum bengalense Retz.	--	--	96.31±24.49	34.20±8.77
Imperata cylindrica (L.) Raeusch.	--	92.89±34.59	19.26±11.09	22.80±7.17
Sorghum halepense (L.) Pers.	9.64±6.80	--	25.68±12.79	13.68±5.56
Kyllinga brevifolia Rottb.	24.09±10.72	--	--	11.40±5.08
Eleusine indica (L.) Gaertn.	4.82±4.81	--	19.26±11.09	9.12±4.54

Species	Upper zone Density (ha^{-1})	Middle zone Density (ha^{-1})	Lower zone Density (ha^{-1})	Overall Density (ha^{-1})
Digitaria ciliaris (Retz.) Koeler	14.45±8.32	--	--	6.84±3.94
Digitaria sanguinalis (L.) Scop.	--	--	19.26±11.09	6.84±3.94
Dinebra retroflexa (Vahl) Panz.	9.64±6.80	13.27±13.24	--	6.84±3.94
Heteropogon contortus (L.) P.Beauv. ex Roem. & Schult.	14.45±8.32	--	--	6.84±3.94
Bambusa bambos (L.) Voss	9.64±6.80	--	--	4.56±3.22
Ischaemum afrum (J.F.Gmel.) Dandy	4.82±4.81	--	--	2.28±2.27
Oloptum miliaceum (L.) Röser & H.R.Hamasha	4.82±4.81	--	--	2.28±2.27
Thysanolaena latifolia (Roxb. ex Hornem.) Honda	4.82±4.81	--	--	2.28±2.27
Typha angustifolia L.	--	13.27±13.24	--	2.28±2.27
Total	**1594.77±82**	**5573.25±196.41**	**2921.46±106.98**	**2341.23±63.47**

5.3.5 Climber

A total number of 28 species of climbers belonging to 24 genera and 12 families was recorded in the Godavari River. Family Convolvulaceae was dominant with maximum number of species (n=8 Species), followed by Fabaceae and Cucurbitaceae (n=7 and 3 Species respectively). Asparagaceae, Asteraceae, Combretaceae, Dioscoreaceae, Menispermaceae, Passifloraceae, Sapindaceae and Vitaceae were represented by single species (Figure. 5.14).

Eight exotic species viz. *Calystegia hederacea, Canavalia rosea, Cocculus carolinus, Cryptostegia madagascariensis, Dioscorea communis, Lathyrus pratensis, Mimosa quadrivalvis*, and *Neonotonia wighti* were recorded in Godavari River. Information on the climber recorded in the Godavari River is highlighted in the Table 5.12.

Richness and diversity of climbers was observed higher in the upper zone (n=23 species, H'=2.82) as compared to lower (n=6 species, H'=1.55) and middle zone (n=3 species, H'= 0.76) of the Godavari River. In upper zone, Convolvulaceae supported eight species and in middle zone Fabaceae supported two species of climbers. Native species of climber were recorded high (n=15 species) in upper zone followed by lower (n=6 species) and middle zone (n=3 species). Only three annual species *viz.*, *Ipomoea hederifolia, Ipomoea purpurea* and *Rhynchosia viscosa* were recorded in the upper zone of the Godavari River. The details of the climber species recorded in the Godavari River during the survey are presented in Appendix 5.6.

Table 5.12 Summary of climber species found in Godavari River

Parameter	Trees			
	Upper Zone	Middle Zone	Lower Zone	Overall
Species	23	3	6	28
Family	10	2	6	12
Order	14	3	6	12
Genus	19	3	6	24
Diversity (Shannon's H')	2.82	0.76	1.55	2.69
Near Threatened (NT)	0	0	0	0
Data Deficient (DD)	0	0	0	0
Not Evaluated (NE)	18	3	5	23
Least Concern (LC)	5	0	1	5
Vulnerable (VU)	0	0	0	0
Native	15	3	6	20
Exotic	8	0	0	8
Annual	3	0	0	3
Perennial	20	3	6	25

5.3.5.1 Richness and diversity of Climber in various segments

Maximum richness of climber species observed in segment 2 (n=11 species) and it was followed segments 3, 4, 7 and 28. The lowest richness was observed in segment 9, 12, 13, 24 and 27 (n=1 species each). Highest diversity of climber was also recorded at segment 2 (H'=2.31). Segments 9, 12, 13, 24 and 27 have no diversity of climber species. Figure 5.15 highlight the richness and diversity of climber at various sampling segments.

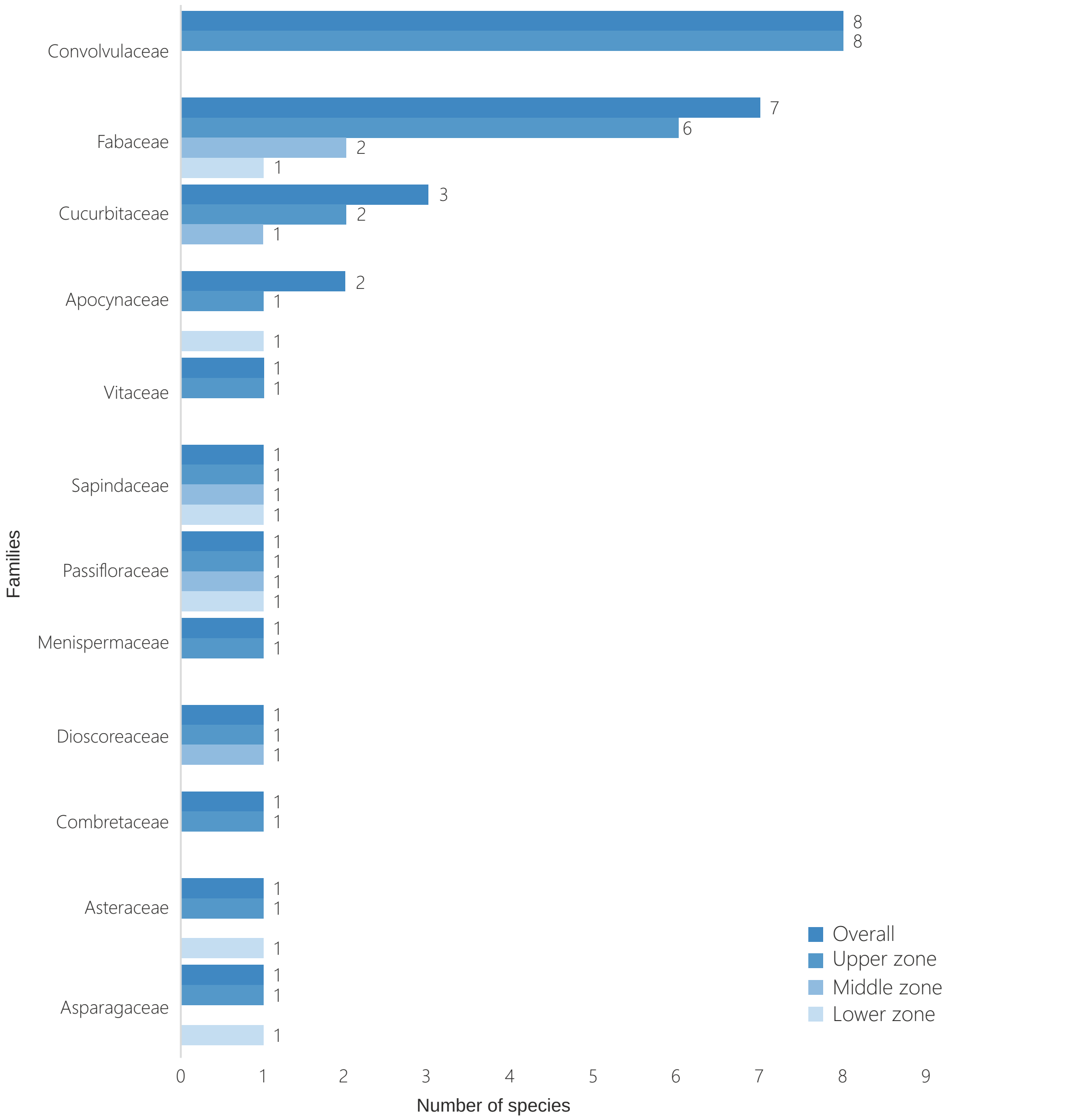


Figure 5.14 Number of species recorded in various families of climber in Godavari River

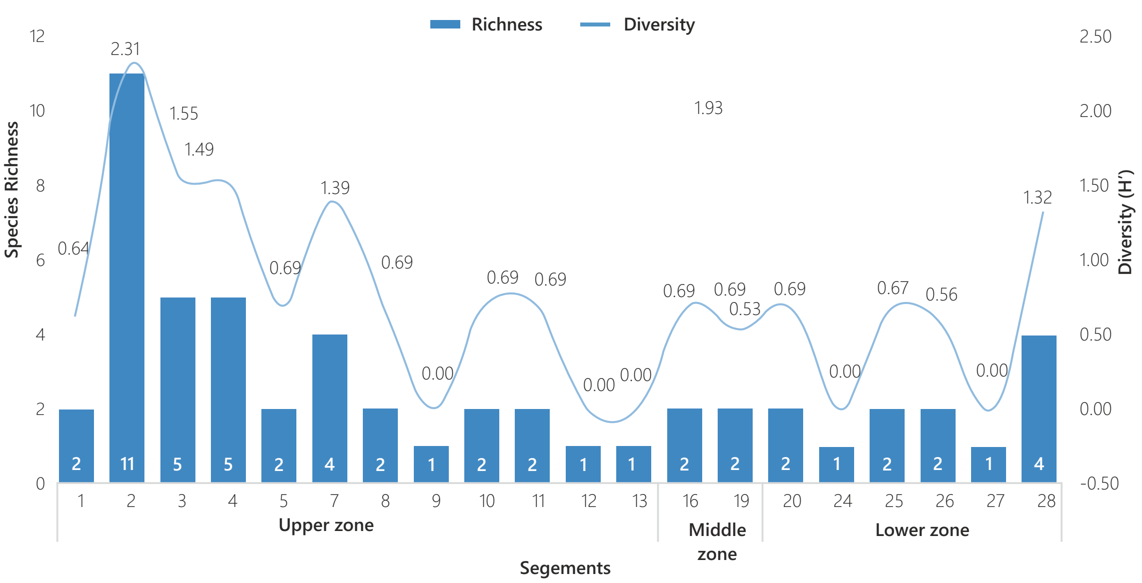


Figure 5.15 Richness and diversity of climbers at various segments in Godavari River

5.3.5.2 Abundance of climber

Clitoria ternatea was the most abundant (61.55±11.71 ha^{-1}) species of climber along the River. It was followed by *Cardiospermum halicacabum* and *Ipomoea hederifolia* with 11.40±5.08 ha^{-1}. *Abrus precatorius, Asparagus racemosus, Calystegia hederacea, Causonis trifolia, Coccinia grandis, Cocculus carolinus, Combretum albidum, Cryptostegia madagascariensis, Dioscorea communis, Distimake dissectus, Distimake quinquefolius, Ipomoea obscura, Lathyrus pratensis, Mimosa quadrivalvis*, and *Neonotonia wightii* with 2.28±2.27 ha^{-1} each were with lowest densities among the recorded species in the Godavari River. The *Clitoria ternatea* was found to be the most abundant species in all three zones of the Godavari River. It was followed by *Ipomoea hederifolia* (24.09±10.72 ha^{-1}), *Ipomoea cairica* (19.27±9.60 ha^{-1}), *Canavalia rosea* and *Cardiospermum halicacabum* equally with 14.45±8.32 ha^{-1} in the upper zone and by *Trichosanthes cucumeroides* (26.54±18.69 ha^{-1}) and *Abrus precatorius* (13.27±13.24 ha^{-1}) in middle zone. In the lower zone *Clitoria ternatea* (57.79±19.07 ha^{-1}) and *Passiflora foetida* (25.68±12.78 ha^{-1}). Table 5.13 provides the density of various climber species recorded in various zones of the Godavari River.

Table 5.13 Density of various climber species reported in various zones of the Godavari River

Species	Upper zone Density (ha^{-1})	Middle zone Density (ha^{-1})	Lower zone Density (ha^{-1})	Overall Density (ha^{-1})
Clitoria ternatea L.	48.18±15.11	106.16±36.90	57.79±19.07	61.55±11.71
Cardiospermum halicacabum L.	14.45±8.32	--	12.84±9.05	11.40±5.08
Ipomoea hederifolia L.	24.09±10.72	--	--	11.40±5.08
Hemidesmus indicus (L.) R.Br. ex Schult.	--	--	25.68±12.78	9.12±4.54
Ipomoea cairica (L.) Sweet	19.27±9.60	--	--	9.12±4.54
Passiflora foetida L.	4.82±4.81	--	19.26±11.08	9.12±4.54
Canavalia rosea (Sw.) DC.	14.45±8.32	--	--	6.84±3.94
Diplocyclos palmatus (L.) C.Jeffrey	14.45±8.32	--	--	6.84±3.94
Convolvulus arvensis L.	9.64±6.80	--	--	4.56±3.22
Ipomoea purpurea (L.) Roth	9.64±6.80	--	--	4.56±3.22
Rhynchosia viscosa (Roth) DC.	9.64±6.80	--	12.84±9.05	4.56±3.22
Sphagneticola trilobata (L.) Pruski	--	--	12.84±9.05	4.56±3.22
Trichosanthes cucumeroides (Ser.) Maxim.	--	26.54±18.69	--	4.56±3.22
Abrus precatorius L.	--	13.27±13.24	--	2.28±2.27
Asparagus racemosus Willd.	--	--	6.42±6.41	2.28±2.27
Calystegia hederacea Wall.	4.82±4.81	--	--	2.28±2.27
Causonis trifolia (L.) Mabb.	4.82±4.81	--	--	2.28±2.27
Coccinia grandis (L.) Voigt	4.82±4.81	--	--	2.28±2.27
Cocculus carolinus (L.) DC.	4.82±4.81	--	--	2.28±2.27
Combretum albidum G.Don	4.82±4.81	--	--	2.28±2.27
Cryptostegia madagascariensis Bojer ex Decne.	4.82±4.81	--	--	2.28±2.27
Dioscorea communis (L.) Caddick & Wilkin	4.82±4.81	--	--	2.28±2.27
Distimake dissectus (Jacq.) A.R.Simões & Staples	4.82±4.81	--	--	2.28±2.27
Distimake quinquefolius (L.) A.R.Simões & Staples	4.82±4.81	--	--	2.28±2.27
Ipomoea obscura (L.) Ker Gawl.	4.82±4.81	--	--	2.28±2.27
Lathyrus pratensis L.	4.82±4.81	--	--	2.28±2.27
Mimosa quadrivalvis L.	4.82±4.81	--	--	2.28±2.27
Neonotonia wightii (Wight & Arn.) J.A.Lackey	4.82±4.81	--	--	2.28±2.27
Total	**231.27±32.83**	**145.97±50.52**	**134.84±31.50**	**182.37±21.03**

5.3.6 Sedges

In total only 4 species of sedges belonging to 3 genera and single family was recorded in the Godavari River. The maximum number of species and richness was recorded in upper zone (n=3 species, H'=0.89), followed by lower zone (n=2 species, H'=0.56) and middle zone (n=1 species, H'=0) respectively. The details of the sedge species recorded in the Godavari River during the survey are presented in Appendix 5.7. All 4 species were represented by Cyperaceae family (Figure 5.16). Among these species *Cyperus rotundus* and *Fimbristylis dichotomata* were terrestrial and perennial in nature and *Schoenoplectiella roylei* was annual, aquatic in nature. The IUCN status of *Schoenoplectiella roylei* and *Cyperus rotundus* is least concern (LC) while the *Fimbristylis dichotomata* is not evaluted (NE). Table 5.14 highlight the information on the sedges recorded in the Godavari River.

Parameter	Sedges Upper Zone	Middle Zone	Lower Zone	Over all
Species	3	1	2	4
Family	1	1	1	1
Order	1	1	1	1
Genus	3	1	2	3
Diversity (Shannon's H')	0.89	0.00	0.56	0.89
Near Threatened (NT)	0	0	0	0
Data Deficient (DD)	0	0	0	0
Not Evaluated (NE)	1	0	1	2
Least Concern (LC)	2	1	1	2
Vulnerable (VU)	0	0	0	0
Native	3	1	2	4
Exotic	0	0	0	0
Annual	1	0	0	1
Perennial	2	1	2	3

Table 5.14 Summary of sedges species found in the Godavari River

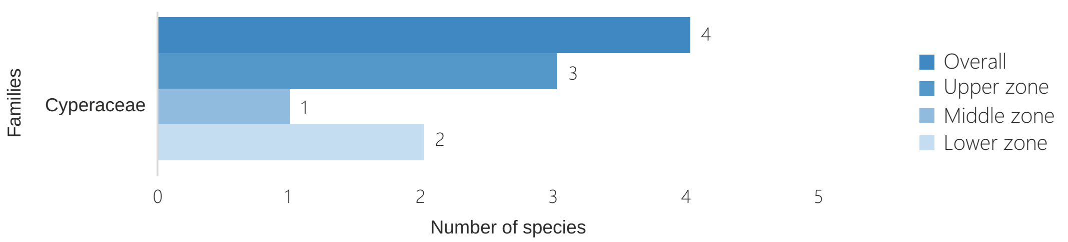


Figure 5.16 Number of species recorded in various families of Sedges in the Godavari River

5.3.6.1 Richness and diversity of sedges

Richness and diversity were observed to be low in all 29 segments of the river. A total number of 4 species of sedges belonging to 3 genera and single families was recorded in the Godavari River (Figure 5.17). Almost all the 29 segments shows no diversity with having richness one.

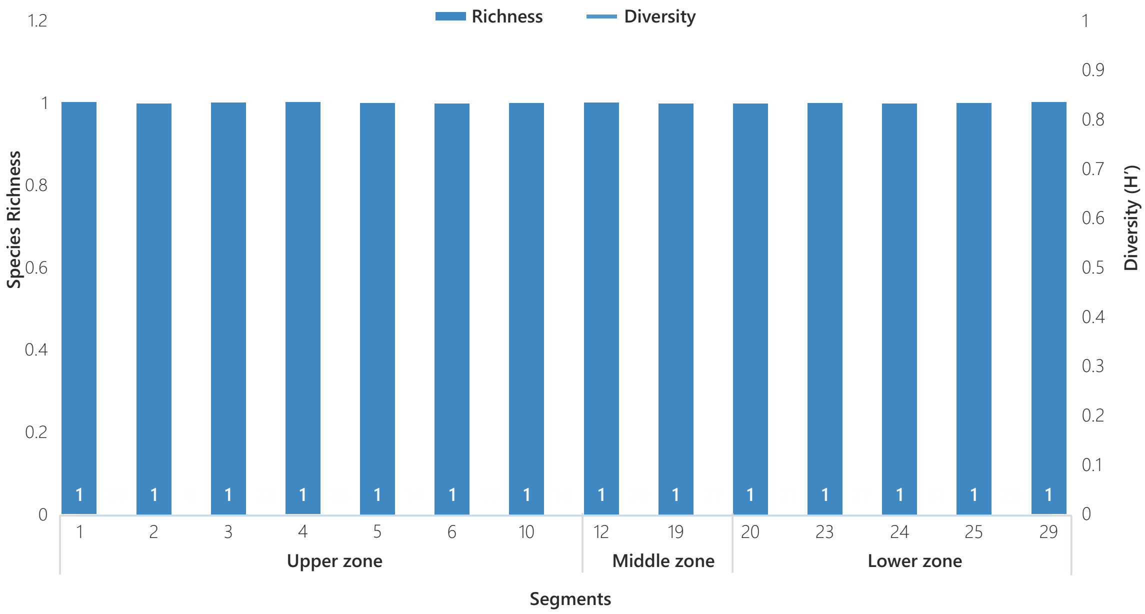


Figure 5.17 Richness and diversity of sedges at various segments in the Godavari River

5.3.6.2 Abundance of sedges

In all three zones of the Godavari River, *Cyperus rotundus*, (47.87±10.35 ha^{-1}) was most abundant species followed by *Cyperus alopecuroides* (6.84±3.94 ha^{-1}), *Fimbristylis dichotomata* (6.84±3.94 ha^{-1}), and *Schoenoplectiella roylei* (4.56±3.22 ha^{-1}). *Cyperus rotundus* is most abundant in all three zone of the Godavari River. Table 5.15 provides the density of various sedges species recorded in various zones of the Godavari River.

Table 5.15 Density of sedges species recorded in various zones of the Godavari River

Species	Upper zone Density (ha^{-1})	Middle zone Density (ha^{-1})	Lower zone Density (ha^{-1})	Overall Density (ha^{-1})
Cyperus rotundus L.	43.36±14.34	39.8±2284	57.79±19.09	47.87±10.35
Cyperus alopecuroides Rottb.	14.45±8.32	--	--	6.84±3.94
Fimbristylis dichotoma (L.) Vahl	--	--	19.26±11.09	6.84±3.94
Schoenoplectiella roylei (Nees) Lye	9.64±6.80	--	--	4.56±3.22
Total	**66.11±12.13**	**67.45±17.82**	**39.81±22.84**	**77.05±21.97**

5.3.7 Invasive Species of Godavari River

A total of 48 invasive species belonging to 41 genera in 18 families were recorded during the survey. The majority of species belong to family Fabaceae (n= 8 species), followed by Asteraceae and Poaceae with 7 and 6 species respectively (Figure 5.18). Herbs constitute the majority (33%) of invasive species followed by trees (21%), Shrubs (8%), Grasses (7%), Climbers (6%) and Sedges (1%) (Figure 5.19). Among the 48 recorded invasive plant, approximately 22.92% are native to Tropical America, followed by Southeast Asia which contributing 8%. Central America, South America, and Tropical/Temperate regions worldwide account for 6% each. India/Sri Lanka and Madagascar contribute 4% each. The remaining 20 species originate from 20 distinct countries (Figure 5.20). There is an urgent need to gather regional data on the diversity of invasive alien plant species in order to study the impact on native vegetation and biodiversity. The present information could serve as baseline information to assess the impact of invasive pressure on the riparian vegetation of the Godavari River.

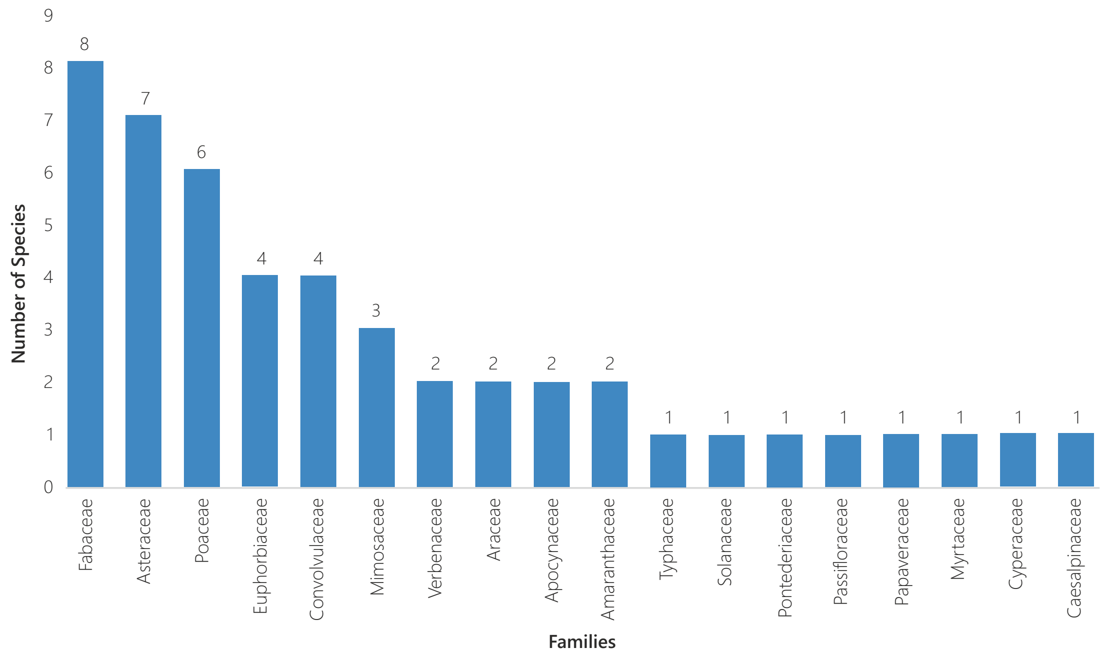


Figure 5.18
Number of invasive plant species recorded in various families in Godavari River

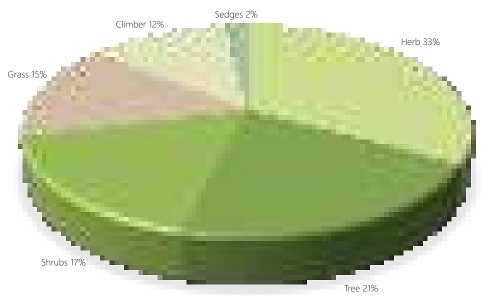


Figure 5.19
Percentage of invasive trees, shrubs, grass, herbs and climbers recorded in the Godavari River

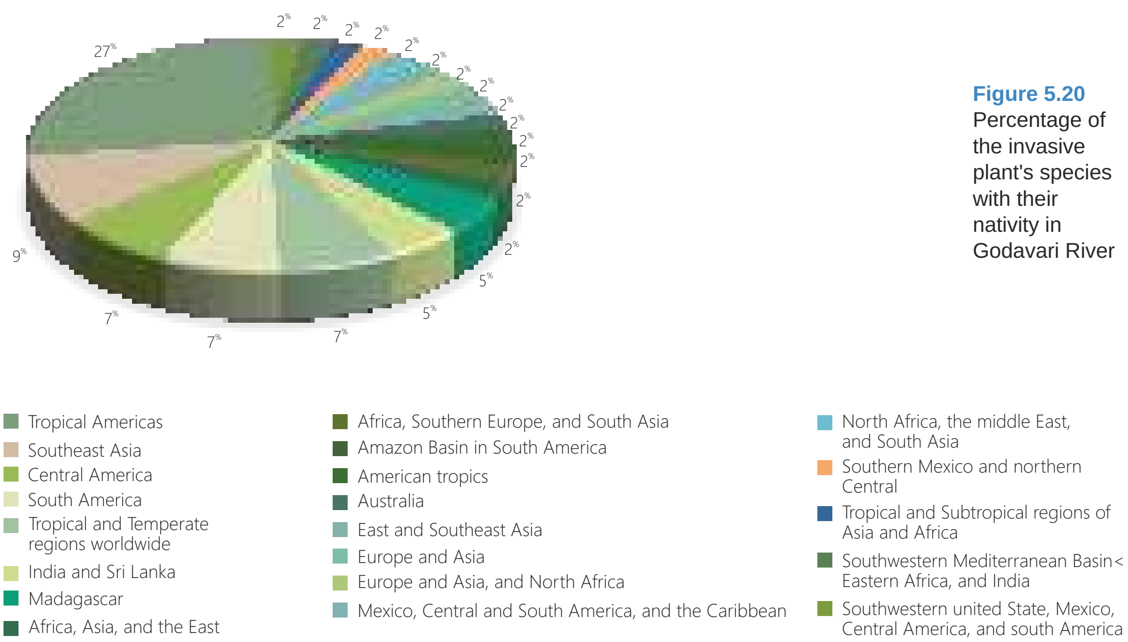


Figure 5.20
Percentage of the invasive plant's species with their nativity in Godavari River

5.3.7.1 Trees

Out of recorded 64 tree species, a total of 10 tree species representing invasive nature that includes; *Acacia nilotica, Albizia lebbeck, Delonix regia, Eucalyptus grandis, Leucaena leucocephala, Parkinsonia aculeata, Prosopis juliflora, Senna siamea, Tectona grandis* and *Vachellia farnesiana*. All the recorded invasive tree belongs to 10 genera and 4 families. The maximum number of invasive tree species belong to the family Fabaceae (n=5 species each) followed by Mimosaceae (n=3 species), Myrtaceae (n=1 species) and Verbenaceae (n=1 species). Majority of the recorded invasive trees species were evergreen, only *Albizia lebbeck*, *Delonix regia* and *Tectona grandis* were deciduous in nature. In term of trees out of the 36 plant species that are globally recognised as the 'World's worst invasive alien species' (Lowe et al. 2000), only *Prosopis juliflora* are recorded from Godavari River. It is estimated that as many as 50% of invasive species, in general, can be classified as ecologically harmful, based on their actual impacts (Richardson et al. 2000).

5.3.7.2 Shrubs

A total of 9 invasive shrub species belonging to 6 families and 7 genera were recorded in the Godavari River. Family Euphorbiaceae supports the highest number of species (n= 3 species), followed by Apocynaceae, Convolvulaceae, Fabaceae, Solanaceae and Verbenaceae with one species each. Except the *Datura metel* and *Ipomoea carnea* remaining species viz., *Jatropha curcas, Jatropha gossypiifolia, Lantana camara, Ricinus communis, Senna auriculata*, and *Calotropis procera* are perennial in nature.

5.3.7.3 Herbs

A total of 16 invasive herbs species belonging to 8 families and 14 genera were recorded along the Godavari River. Maximum number of species belong to the family Asteraceae (n= 6 species) followed by Amaranthaceae, Araceae, and Fabaceae with two species. However, Caesalpinaceae, Euphorbiaceae, Papaveraceae, and Pontederiaceae represented with single species. *Ageratum conyzoides, Amaranthus spinosus, Chromolaena odorata, Cosmos caudatus, Parthenium hysterophorus, Senna occidentalis, Senna tora, Tridax procumbens* and *Xanthium strumarium* were annual in nature while the remaining species viz., *Alternanthera philoxeroides, Argemone mexicana, Colocasia esculenta, Euphorbia hirta, Pistia stratiotes, Pontederia crassipes* and *Senna obtusifolia* were perennial.

5.3.7.4 Grasses

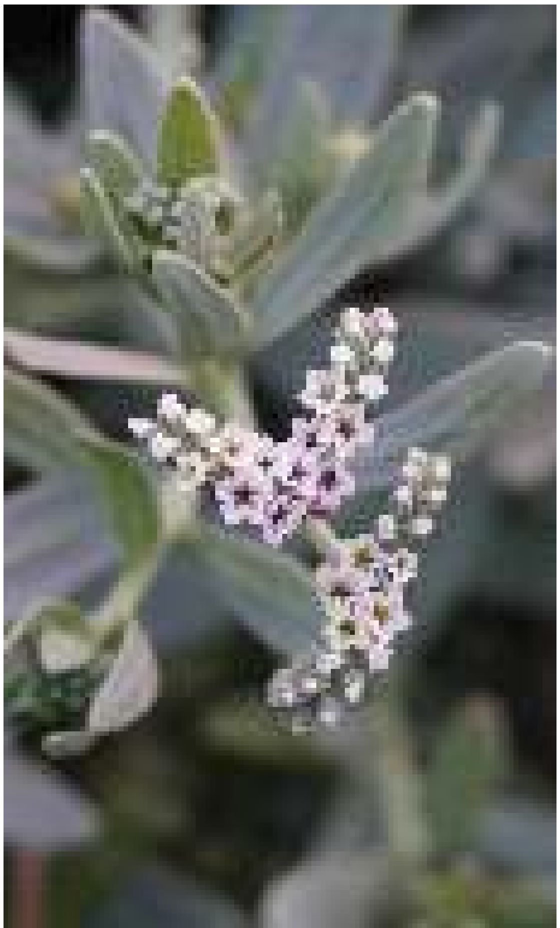
A total of 7 invasive grass species belonging to 7 genera and 2 families were recorded in the Godavari River. Highest number of species belong to the family Poaceae (n= 6 species), followed by Typhaceae (n= 1 Species). Family Typhaceae was represented by single species *Typha angustifolia*., whereas Poaceae family was represented by *Cenchrus ciliaris*, *Cynodon dactylon*, *Imperata cylindrica*, *Saccharum spontaneum*, *Setaria verticillate*, and *Sorghum halepense*.

5.3.7.5 Climber

A total number of 6 climber species belonging to 5 genera and 4 families was recorded in the Godavari River. Family Convolvulaceae was dominant with maximum number of species (n= 3 Species), followed by Apocynaceae, Asteraceae and Passifloraceae Vitaceae were represented by single species. Of the recorded 6 invasive climber only *Ipomoea purpurea* were annual and remaining five species viz., *Convolvulus arvensis, Cryptostegia madagascariensis, Ipomoea cairica, Passiflora foetida* and *Sphagneticola trilobata* were perennial in nature.

5.3.7.6 Sedges

In total only one species of *Cyperus rotundus* belonging, to genera Cyperus and family Cyperaceae was recorded in the Godavari River as invasive species. The IUCN status of *Cyperus rotundus* is least concern (LC).



5.4 Discussion

The floristic assemblage is one of the key characteristics of the plant community where the number of species and their individuals in a community reflect its gene pool and adaptation potential. Furthermore, the floristic assemblage and diversity patterns of plant communities are a prerequisite to understand the general structure, function, and composition of any ecosystem. The current study focuses on evaluating the diversity, abundance, and richness of trees, herbs, shrubs, grasses, climbers, sedges and the biomass of tree species in the Western Ghats of the Godavari River. The present study enumerated a total of 242 plants species including 64 trees (26%), 20 shrubs (8%), 101 herbs (42%), 25 grasses (10%) 28 climbers (12%), and 4 sedges (2%) were observed from the Godavari River. 25 % of plants were exotic with the majority of them were from Tropical America in origin. Notably, our findings reveal that within the Godavari River herbs are the dominating species representing 42% of the total population, followed by trees species (26%). However, grasses, shrubs, climbers and sedges comprised a lowered proportion but they still make a significant, part of the floristic assemblage. The species diversity depends upon the adaptation of species which increases with the stability of the community (Singh et al., 1994). In the present study, we found that our recorded species (n = 242 species) are comparatively higher than the previously reported authors as 151 species from East Godavari District, Andhra Pradesh (Tarakeswara et al., 2018), 110 species from Godavari Valley, Telangana, India (Suthari and Raju, 2018), 143 species from Tropical Forests of Siwaram Wildlife Sanctuary, Telangana, India (Murthy et al., 2015), etc. Such wide variation may occur due to the method of data collection and characteristic abiotic factors likewise temperature, rainfall, physico-chemical parameters of soil, and biotic factors likewise overgrazing, collection of fuel wood, timber, and non-timber forest products including fruit and seeds. However, this highly floristic assemblage in our study indicates a robust and adaptable ecosystem, fostering stability by enhancing ecological functions, supporting diverse wildlife habitats, and ensuring genetic diversity for long-term sustainability.

In tropical forests, plant diversity assessments primarily focus on tree species diversity rather than the other life forms due to their fundamental role in the ecosystem, with variations influenced by geographical factors, anthropogenic pressures, and climate (Suthari and Raju, 2018). The investigation revealed that tree species richness was more in upper zone (n=44 species), however, diversity peaked in the lower zone (H'=2.95), compared to both the upper zone (H'=1.88) and middle zone (H'=1.57). Notably, Maximum richness of tree species was observed at segment 5 (n=16 species) and diversity was observed maximum at segment 24 (H'= 2.37). Although in the case of shrubs, the upper zone harboured the highest shrub richness (n=18 species) compared to the lower (n=9) and middle (n=8 species) zones. The lower zone exhibited greater shrub diversity (H'=1.71). Segments 2 show maximum shrub richness (n= 9 species), while segments 2 (H'= 1.76) demonstrated high shrub diversity followed by segment 6 (H'= 1.64).

In case of herbs, investigation reveals that maximum species richness was observed in upper zone (n=85 species), and the maximum species diversity was observed at lower zone (H'= 3.22). However, in term of segments the maximum richness was recorded at segment 26 (n=31 species), followed by segment 2 (n=28 species) and the maximum diversity was also observed at segment 26 (H'=2.96) followed by segment 2 (H'=2.65). Investigation reveals that the upper zone harboured the highest count and richness of grass species (n= 19 species, H'= 2.06) followed by lower zone (n= 14 species) and middle zone (n= 12 species). The middle zone shows better diversity (H'=1.90) as compare to lower zone (H'=1.59). In case of segments the maximum richness and diversity was observed at segment 19 (n=10 species, H'=1.93). Richness and diversity of climbers was observed higher in the upper zone (n=23 species, H'=2.82) as compared to lower (n=6 species, H'=1.55) and middle zone (n=3 species, H'= 0.76). Notably, the maximum richness of climber species observed at segment 2 (n= 11 species, H'=2.31). The maximum number of sedges species and richness was recorded in upper zone (n=3 species, H'=0.89), followed by lower zone (n=2 species, H'=0.56) and middle zone (n=1 species, H'=0) respectively.

Species richness and diversity in the middle zone were reduced, likely due to anthropogenic pressures such as firewood collection, cattle grazing, loping, soil removal and introduction of invasive weeds into the study area. Our findings are in line with the previously published reports from Suruli Falls Forest of Western Ghats (Naveenkumar and Sundarapandian, 2018), Nokrek biosphere reserve (Sangma and Mishra, 2017), Coromandel coast (Anbarashan and Parthasarathy, 2013), tropical dry deciduous forest of western India (Kumar et al., 2010). The Table 5.16 highlights the tree species reported from the riparian zone of the Godavari River.

Along the Godavari River, the average tree density was 98.50±4.11 trees per hectare. *Prosopis juliflora*, emerging as the dominant species with 42.61±12.85 trees per hectare and an impressive Importance Value Index (IVI) of 86.80. Shrub density measured an average of 88.88±5.29 ha^{-1}, with *Lantana camara* prevailing at 99.92±26.73 ha^{-1}. The individual plant density of herb, grasses, climber and sedges were recorded 7698.48±115.13 indi/ha, 2341.23±63.47 indi/ha, 182.37±21.03 indi/ha, and 77.05±21.97 indi/ha, respectively. Among the vegetation in all three zones of the Godavari River, *Alternanthera sessilis* was the most abundant herb with 1791.83±43.52 individuals per hectare. In the grass category, *Cynodon dactylon* dominated with 747.74±36.76 individuals per hectare. *Clitoria ternatea* was the most prevalent climber, recorded at 61.55±11.71 individuals per hectare, while *Cyperus rotundus* was the most abundant sedge with 47.87±10.35 individuals per hectare.

Among the major threats faced by India's native plant species is the one posed by Invasive Species. These invasive are non-native organisms introduced outside from their natural habitats, either through natural processes or via human activities (Early et al., 2016). They are one of the major threats to global and local biodiversity (Pejchar and Mooney, 2009), ecosystem services, and human well-being. A total of 48 invasive species belonging to 41 genera in 18 families were recorded during the survey. The majority of species belongs to family Fabaceae (8 species), followed by Asteraceae and Poaceae with 7 and 6 species respectively. Herbs constitute the majority (33%) of alien species followed by trees (21%), Shrubs (8%), Grasses (7%), Climbers (6%) and Sedges (1%). In forest ecosystems, the threats caused by IAS include hybridization, transmission of diseases, and species competition (Langmaier and Lapin, 2020). They also attract pollinators and dispersers away from native species (Tireman, 1916), thus posing indirect competition to the native species. So, there is an urgent need for an authoritative database on invasive plant species to monitor their spread and impact in various regions and to plan appropriate management strategies. The dominance of exotic herbs and climbers may particularly affect the ground and mid-canopy layers, while exotic trees and shrubs can alter the forest structure and composition.

These findings contribute to a comprehensive understanding of the vegetation structure in the Godavari River ecosystem. Abundant plant communities sustain diverse habitats, fostering intricate food webs, promoting ecosystem stability and also reflecting its significant density, dominance, and abundance related to other species. The present result pointed out that overall tree above-ground biomass is averaged 6.98±0.53 Mg ha^{-1}. The lower zone exhibiting a significantly higher amount at 10.67±1.62 Mg ha^{-1}, followed by the upper and middle zones. Brown and Lugo (1990), concluded that the total amount of accumulated biomass in forest ecosystems may vary with variation in biophysical characteristics, microclimate, and level of anthropogenic disturbances.

The results of our comprehensive survey have revealed the diverse tapestry of plant life thriving along the Godavari River. The high species richness of plants in this area not only contributes to the region's biodiversity but also plays a pivotal role in supporting threatened and endemic flora. This diversity is not only a testament to the ecological health of the region but also holds significant implications for the wider biodiversity of Godavari surroundings. As we acknowledge the potential of Godavari riverine vegetation in shaping the microclimate and sustaining diverse species, it becomes imperative to prioritize conservation efforts to ensure the long-term health of this vital ecosystem.

Table 5.16: Status of floral assemblage in the Godavari region

S.No.	Study area	Trees	Shrub	Herbs	Climber	Grass	Total species	Reference
1	Overall in the Godavari Basin	98	31	54	16	14	213	NRCD-WII Godavari Riverscape (2022)
2	Western ghats of Nashik Maharashtra	30	32	68	12	_	142	Sangle et al., (2023)
3	Gautala Reserve Forest Aurangabad Maharashtra	41	24	12	6	_	91	Mirza and Patil (2020)
4	Andhra Pradesh	502	245	1564	290	_	2601	Pullaiah et al., (2008)
5	Jalna District, Maharashtra	11	9	15	1	_	36	Deshmukh et al., (2011)
6	Theraban, Somthana Region, Nanded, Maharastra	2	5	7	3	_	17	Shinde et al., (2022)
7	Kawal Wildlife Sanctuary Adilabad Telangana	15	5	4	1	_	25	Murthy et al., (2010)
8	Warangal City Telangana	4	9	82	2	_	97	Kommidi et al., (2021)
9	Medicinal plant in East Godavari	24	24	32	5	1	90	Divya et al., (2015)
10	Forest products of west Godavari district, Andhra Pradesh	76	34	25	7	6	148	Rao et al., (2014)

References

Alengebawy A, Abdelkhalek ST, Qureshi SR, and Wang MQ (2021) Heavy metals and pesticides toxicity in agricultural soil and plants: Ecological risks and human health implications. Toxics, 9(3), 42.

Anbarashan M and Parthasarathy N (2013) Tree diversity of tropical dry evergreen forests dominated by single or mixed species on the Coromandel coast of India. Tropical Ecology, 54(2), 179-190.

Baishya R and Barik S (2011) Estimation of tree biomass, carbon pool and net primary production of an old-growth Pinus kesiya Royle ex. Gordon Forest in north-eastern India. Annals of Forest Science, 68(4), 727-736.

Banik B, Deb D, Deb S and Datta BK (2018) Assessment of Biomass and Carbon Stock in Sal (*Shorea robusta* Gaertn.) Forests under Two Management Regimes in Tripura, Northeast India. Journal of Forest and Environmental Science, 34, 209-223.

Bharambe KP, Shimizu Y, Kantoush SA, Sumi T and Sabe M (2023) Impacts of climate change on drought and its consequences on the agricultural crop under worst-case scenario over the Godavari River Basin, India. Climate Services, 32, 100415.

Bhattacharya S, Paul A, Chattopadhyay D and Mukhopadhyay A (2012) Impact of climate change on the water resources of India: A review of the perspectives for environment, health and economy. In Proceedings of the Vith World Aqua Congress 2012, Water-Vision 2050, November 28-30, 2012, New Delhi, India, pp. 27-36.

Bilby RE (1988) Interactions 'between aquatic and terrestrial systems. Pages 13-29 in KJ Raedeke, editor. Streamside management: riparian wildlife and forestry interactions. University of Washington Press, Seattle, Washington, USA.

Brown, S and Lugo, AE (1990) Tropical secondary forests. Journal of tropical ecology, 6(1), 1-32.

Chambers JQ, Santos JD, Ribeiro RJ and Higuchi N (2001) Tree damage, allometric relationships, and above-ground net primary production in central Amazon Forest. Forest Ecology and Management, 152(1–3), 73-84.

Chen Q, Wu W, Zhao T, Tan W, Tian J and Liang C (2019) Complex gene regulation underlying mineral nutrient homeostasis in soybean root response to acidity stress. Genes, 10, 402.

Cummins KW (1980) The multiple linkages of forest to streams. Pages 191-198 in RH Waring, editor. Forests: fresh perspectives from ecosystem analysis. Proceedings of the 40th Annual Biology Colloquium. Oregon State University Press, Corvallis, Oregon, USA.

Das S, Kandekar AM and Sangode SJ (2022) Natural and anthropogenic effects on spatio-temporal variation in sediment load and yield in the Godavari basin, India. Science of The Total Environment, 845, 157213.

Deshmukh RR, Rathod VN and Pardeshi VN (2011) Ethnoveterinary medicine from Jalna district of Maharashtra state. Indian Journal of Traditional Knowledge, 10(2), 310-313.

Divya K, Mary NR and Padal SB (2015) Ethno-medicinal plants used in East Godavari District, Andhra Pradesh, India. International Journal of Pharmacological Research, 5(1), 293-300.

Early R (2016) Global threats from invasive alien species in the twenty first century and national response capacities. Nature Communication. DOI: 10.1038/ncomms12485

Eaton BC, Church M and Millar RG (2004) Rational regime model of alluvial channel morphology and response. Earth Surface Processes and Landforms, 29, 500–529.

El-Sheekh M, Abdel-Daim MM, Okba M, Gharib S, Soliman A and El-Kassas H (2021) Green technology for bioremediation of the eutrophication phenomenon in aquatic ecosystems: a review. African Journal of Aquatic Science, 46(3), 274-292.

Forest Survey of India (2016) State of Forest Report. Forest Survey of India, Ministry of Environment and Forests, Government of India.

Guo R, Yang Z, Li F, Yan C, Zhong X, Liu Q, Xia X, Li H and Zhao L (2015) Comparative metabolic responses and adaptive strategies of wheat (Triticum aestivum) to salt and alkali stress. BMC Plant Biology, 15, 170.

Ho YC, Show KY, Guo XX, Norli I, Abbas FA and Morad N (2012) Industrial discharge and their effect on the environment. Industrial Waste, 1-33.

Hould-Gosselin G, Rousseau AN, Gumiere SJ, Hallema DW, Ratté-Fortin C, Thériault G and Van Bochove E (2016) Modeling the sediment yield and the impact of vegetated filters using an event-based soil erosion model—a case study of a small Canadian watershed. Hydrological Processes, 30, 2835-2850.

Kalair A, Abas N, Saleem MS, Kalair AR and Khan N (2021) Role of energy storage systems in energy transition from fossil fuels to renewables. Energy Storage, 3(1), e135.

Kantharajan G, Govindakrishnan PM, Chandran R, Singh RK, Kumar K, Anand A and Lal KK (2023) Anthropogenic risk assessment of riverine habitat using geospatial modeling tools for conservation and restoration planning: a case study from a tropical river Pranhita, India. Environmental Science and Pollution Research, 30, 37579-37597.

Kommidi S, Koppula T and Mohammed SYM (2020) Study of Invasive Plant Species Distribution in Warangal City, Telangana, India.(2021). Int. J. Life Sci. Pharma Res, 11(1), 179-187.

Kumar JN, Kumar RN, Bhoi RK and Sajish PR (2010) Tree species diversity and soil nutrient status in three sites of tropical dry deciduous forest of western India. Tropical Ecology, 51(2), 273-279.

Langmaier M and Lapin K (2020) A systematic review of the impact of invasive alien plants on forest regeneration in European temperate forests. Frontiers in Plant Science, 11, 524969.

Li L, Guo Q, Tao S, Kelly M and Xu, G (2015) Lidar with multi-temporal MODIS provide a means to upscale predictions of forest biomass. ISPRS Journal of Photogrammetry and Remote Sensing, 102, 198-208.

Lu D, Batistella M and Moran E (2005) Satellite estimation of aboveground biomass and impacts of forest stand structure. Photogrammetric Engineering & Remote Sensing, 71(8), 967-974.

Mirza AN and Patil SS (2021) Seasonal Plant Diversity of Gautala Reserve Forest, District Aurangabad. Applied Ecology and Environmental Sciences, 9(1), 92-101.

Misra R (1968) Ecology workbook. Oxford and IBH Publishing Co., New Delhi.

Murthy EN, Madhav NV and Sathanna G (2015) Observations on patterns of vegetation in Tropical Forests of Siwaram Wildlife Sanctuary, Telangana state, India. Department of Botany, International Science Congress Association.

Murthy EN, Pattanaik C, Reddy CS and Raju VS. (2010) Piscicidal plants used by Gond Tribe of Kawal Wildlife Sanctuary, Andhra Pradesh, India. Indian Journal of Natural Products and Resources 1.01: 97-101.

Nagajyoti PC, Lee KD and Sreekanth TVM (2010) Heavy metals, occurrence and toxicity for plants: a review. Environmental Chemistry Letters, 8, 199-216.

Navasakthi S, Pandey A, Dandautiya R, Hasan M, Khan MA, Perveen K and Qamar O (2023) Assessment of Spatial and Temporal Variation in Water Quality for the Godavari River. Water, 15, 3076.

Naveenkumar J and Sundarapandian S (2018) Assessment of tree diversity in distinctive deciduous forests of Suruli falls, Southern Western Ghats. Journal of Applied and Natural Science, 10(4), 1085-1093.

NRCD-WII (2022) Godavari Riverscape: Ecological status and trends. Ganga Aqualife Conservation Monitoring Centre, Wildlife Institute of India, Dehradun. Uttarakhand, India. pp. 141.

Okereke JN, Ogidi OI and Obasi KO (2016) Environmental and health impact of industrial wastewater effluents in Nigeria-A Review. International Journal of Advanced Research in Biological Sciences, 3(6), 55-67.

Pandey SK and Shukla RP (2001) Regeneration strategy and plant diversity status in degraded sal forests. Current Science, 81, 95-102.

Pandey SK and Shukla RP (2003) Plant diversity in managed Sal (Shorea robusta) forests of Gorakhpur India: species composition regeneration and conservation. Biodiversity and Conservation, 12, 2295-2319.

Pandey SK and Shukla RP (2005) Plant community and diversity patterns within the forested landscape of north-eastern U.P. Indian Forester, 131, 1217-1226.

Pejchar L and Mooney HA (2009) Invasive species, ecosystem services and human well-being. Trends in ecology & evolution, 24(9), 497-504.

Penman J, Gytarsky M, Hiraishi T, Krug T, Kruger D, Pipatti R, Buendia L, Miwa K, Ngara T, Tanabe K and Wagner F (2003) Good practice guidance for land use, land-use change and forestry.

Pullaiah T, Rani SS, Murthy KS and Karuppusamy S (2016) Floristic and ethnobotanical studies in andhra pradesh. Indian Ethnobotany: Emerging Trends, 138.

Rajpar MN, Rajpar AH and Zakaria M (2022) Riverine forest as a significant habitat to harbor a wide range of bird species. Brazilian Journal of Biology, 84, e256160.

Rao PS, Neelima P, Lakshminarayan K and Kumar OA (2014) Important plant-based non-timber forest products of West Godavari District, Andhra Pradesh, India. Scholars Research Library, 4(2), 33-42.

Reddy CS, Varma Y, Brahmam M and Raju V (2008) Prioritisation of endemic plants of Eastern Ghats for Biological conservation. In Proceedings of the National Seminar on Conservation of Eastern Ghats. EPTRI, Hyderabad (pp. 3-13).

Richardson JS and Moore RD (2010) Stream and riparian ecology. In Compendium of forest hydrology and geomorphology in British Columbia. RG Pike, TE Redding, RD Moore, RD Winker, and KD Bladon (editors). BC Ministry of Forests and Range, Forest Science Program, Victoria, BC, and FORREX Forum for Research and Extension in Natural Resources, Kamloops, BC Land Management Handbook (No. 66, pp. 441-460).

Sangale MP, Kshirsagar SR and Shinde HP (2023) Floristic studies on some rare plants in Western Ghats of Nasik District. Sustainability, Agri, Food and Environmental Research, (ISSN: 0719-3726).

Sangma TE and Mishra BP (2017) Effect of anthropogenic disturbance on the tree diversity of Nokrek biosphere reserve in Meghalaya, India. Journal of Agroecology and Natural Resource Management, 4(3), 196-200.

Shinde SS, Raut SD and Gachande BD (2022) Herbal medicinal plants active against COVID-19 used by tribal communities from Nanded district (MS), India. Int J Pharm Pharm Sci, 14(3), 27.

Singh R, Thakur GC and Sood VK (1994) Phytosociology and resource utilization by different forest trees in South-eastern slopes around Shimla, Himachal Pradesh. Indian Forester, 120, 1108-1117.

Singh RK, Jain MK and Gupta V (2022) Impact of climate change on runoff regime of the Godavari River in India. Sustainable Water Resources Management, 8, 69.

Suthari S and Raju VS (2018) Tree species composition and forest stratification along the gradients in the dry deciduous forests of Godavari valley, Telangana, India. European Journal of Ecology, 4(1), 1-12.

Swanson FJ, Gregory SV, Sedell JR and Campbell AG (1982) Land-water interactions: the riparian zone. Pages 267-291 in RL Edmonds, editor. Analysis of coniferous ecosystems in the western United States. Hutchinson Ross Publishing Company, Stroudsburg, Pennsylvania, USA.

Tarakeswara NM, Premavani D, Suthari S and Venkaiah M (2018) Assessment of tree diversity in tropical deciduous forests of Northcentral Eastern Ghats, India. Geology, Ecology, and Landscapes, 2(3), 216-227.

Zhang C, Yi X, Zhou F, Gao X, Wang M, Chen J, Huang J and Shen C (2020) Comprehensive transcriptome profiling of tea leaves (Camellia sinensis) in response to simulated acid rain. Scientia Horticulturae, 272, 109491.

Zhang Y, Zhao Q, Cao Z and Ding S (2019) Inhibiting effects of vegetation on the characteristics of runoff and sediment yield on riparian slope along the lower Yellow River. Sustainability, 11(13), 3685.

Plate 1: Trees, Shrubs, Herbs, Grass, Climber and Sedges recorded from Godavari River during survey

1 *Azadirachta indica*

2 *Jatropha gossypiifolia*

3 *Cleome chelidonii*

4 *Elusine indica*

5 *Passiflora foetida*

6 *Cyperus alopecuroides*

06

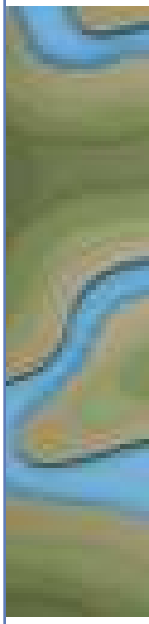
ICHTHYOFAUNA

06

ICHTHYOFAUNA

Abstract

This study documents the fish diversity, assemblage structure, distributional pattern and composition of different sampling sites along the entire stretch of the Godavari River. However, only a limited number of studies have highlighted the status of fish fauna in the Godavari River. We conducted a rapid survey of fish between July 2022 to September 2022 and November 2022 to March 2023, and recorded a total of 60 fish species representing 15 families and 11 orders, with a diversity value of 1.76 and an abundance of 4.88 fish/hour. Family Cyprinidae was the dominant family (n=27), followed by Danionidae (n=7) and Bagridae (n=6). Three vulnerable fish species viz., Oreochromis mossambicus, Cyprinus carpio, Wallago attu, and two near-threatened (NT) fish species, viz., Ompok bimaculatus and Chitala chitala were recorded during the survey. Five species viz. Cyprinus carpio, Hypophthalmichthys nobilis, Oreochromis mossambicus, Oreochromis niloticus, and Pygocentrus nattereri were exotic/ invasive to the Godavari River. Correspondence Canonical Analysis (CCA) indicated a positive correlation of fish abundance with turbidity, width, pH, and depth, while negatively associated with conductivity, TDS, boulder, and pebble substrate. Fish fauna of Godavari River is threatened by a variety of anthropogenic pressures such as restricted movement due to dams and water abstraction, indiscriminate fishing, and sewage and industrial pollution. Information on the status and distribution of fish fauna facilitates conservation initiatives. About 680 km of the Godavari River stretch contains suitable habitats for three to seven species. Adequate protection of these stretches and collaboration efforts of various stakeholders are required to conserve the fish in the Godavari River.



6.1 Introduction

Freshwater fishes serve as important component in aquatic ecosystems providing indispensable services that offer advantages to the environment and humanity. Whether tiny minnows or formidable salmon, these aquatic creature contribute significantly to water purification sustaining food chains and maintaining vibrant aquatic ecosystems. Fish often act as bio-indicators, offering insights into the pollution levels within aquatic ecosystems (Gopal et al.,1997). They are also used in assessing and monitoring heavy metal pollution (Authman et al., 2015). Additionally, freshwater fishes contribute to livelihood and are food sources for millions of people worldwide (Kelleher, 2012, Lynch et al., 2016). Fishes serve as the major source of protein and contain a large number of health-beneficial vitamins, minerals, and fatty acids. Eating fish once a week significantly reduces coronary heart disease risk compared to the non-eating fish group (Kromhout et al., 2012). An old tradition of giving Murrel fish (*Channa sp.*) seed with herbal paste to cure bronchial asthma has been practiced for 170 years in the southern region of India (Indian Express, 2018). Since ancient times, freshwater fishes have been considered blessed in many parts of India (Nautiyal, 2005).

Yet freshwater fish population are decline due to various anthropogenic pressures such as restricted exchange of gene due to dams, water abstraction, indiscriminate fishing, sewage and industrial pollution in multiple rivers of India. Hydrological barriers like dams, which also affect the migration patterns of anadromous fish like salmon and hilsa, as well as catadromous fish like eels. These barriers also reduce fish diversity by making the waters unsuitable for life by lowering oxygen levels. (Kroger, 1973; Zohary and Ostrovsky, 2011, Wu et al., 2019). Dams also cause local extinction of species e.g., Mahseer loss due to the Tehri dam on the Bhagirathi River (Sarkar et al., 2015). Several types of pollution, including pesticide pollution, affect fishes critical life stages, i.e., fish fry, larvae, and fingerlings. Additionally, pesticides and heavy metal pollution affect the vital organs of fish, such as gills, kidneys, and liver, impacting reproduction (Khoshnood, 2017). Excessive fishing pressure removes fish faster than they can reproduce, leading to declining population sizes and community structure (Sarkar et al., 2013). However, climate change further aggravates the detrimental situations.

The Godavari River is the most extensive river system in peninsular India and is regarded as the country's second-longest river after the Ganges (1,465 kilometers). The river flows through diverse biogeographic zones such as the Western Ghats, the Deccan peninsula, and the east coast. Yet, it sustains low ichthyofauna diversity due to high anthropogenic pressures. For instance, In Maharashtra, Balkhande and Kulkarni (2015) reported 18 fish species from Dhangar Takli, Parbhani district (Shillewar and Totawar, 2017) recorded 21 species from Vishnupur dam, Nanded District. In Ahilyanagar, (Khobragade, 2016) reported the presence of 21 species at the confluence of Pravara and Godavari Rivers. Rankhamb (2011) reported 26 species of fish in Mudgal, Pathri district. In the Godavari basin, (Heda, 2009) reported 47 species in two northern, and eastern Godavari basin rivers, viz., Kathni and Adan rivers. Khedkar et al., (2014) highlighted the presence of 114 species of fish in the Godavari basin. The river supports a wide range of threatened fish diversity including the endangered *Labeo potail, Puntius fraseri, Thynnichthys sandkhol*, and *Silonia childreni* as well as the vulnerable fishes such as *Cyprinus carpio, Wallago attu, Oreochromis mossambicus, Cirrhinus cirrhosus, Hypselobarbus kolus, Puntius arenatus, Salmostoma horai, Tenualosa toli* and *Hyporhamphus xanthopterus* (Khedkar et al., 2014)

Moreover, the Godavari River is threatened with a multitude of anthropogenic pressures owing to its location and it is flowing through over developing states of India, viz., Maharashtra, Telangana, Andhra Pradesh. The human population rises in the districts along the course of River Godavari (from 1,63,48,837 in 1951 to 5,12,47,255 in 2011) allied with urbanization and industrialization in Nashik, Ahilyanagar, Aurangabad, Jalna, and Karimnagar district has deteriorated the water availability and quality of Godavari River affecting the habitat of fishes (Ishwar and Zainab, 2011). Additionally, the abstraction of water during the construction of a large number of dams, such as Karanjwan Dam, Jayakwadi Dam, and Sriram Sagar Dam, has impacted the ecological flow of fish in Godavari River, leaving little water for the survival of fish (Central Water Commission, 2012). Moreover, over-exploitation coupled with a population of invasive species such as *Oreochromis mossambicus, Clarias gariepinus, Pangasianodon hypophthalmus, Pygocentrus nattereri, Gambusia affinis,* and *Hypophthalmichthys nobilis* are impacting the richness and abundance of native fishes (Sugunan 2002, Kharat et al., 2003, Singh and Lakra, 2006, Krishna et al., 2011, Singh and Lakra, 2011). All these anthropogenic factors cumulatively affect fish's survival in the Godavari River.

Yet studies on the status and distribution of the fish fauna are very limited in the Godavari River and restricted to small stretches of the Godavari River (Balkhande and Kulkarni 2015, Khobragade 2016, Shillewar and Totawar 2017, Prasad et al. 2019, Prasad et al., 2020). The current chapter highlights the status, composition, and distribution of fishes in the Godavari River. The study also provides information on the stretches of fish species suitable for facilitating ichthyofauna conservation in the Godavari River.

6.2 Methods of Assessment

Fish were surveyed in the 5 km segments by laying transects of 1 km. On each transect, gill nets were deployed for a 2-hour between 08:00 and 10:00 hours at the start and end of the transect. Concurrently, 20 cast nets were casted with a 5-10 min settling time at various locations along the transect (Figure 6.1). For each captured fish, data on species name, number of individuals, total length (from mouth to the end of caudal fin), standard length (from mouth to the beginning of the caudal fin), and weight were recorded. Following the data collection, the fish were released back into the river. Any unidentified species were photographed, carefully collected, and preserved in 10% formalin for subsequent identification in laboratory. The online resource "Eschmeyer's Catalogue of Fishes" from the California Academy of Sciences and a fish identification manual by (Jayaram, 2010) were consulted to ensure accurate species identification.

The data collected during the survey was used to determine the richness and diversity of fish in Godavari River. The diversity of the fish was determined by using the Past Software. The abundance of each species was assessed by determining the value of catch per unit effort (CPUE) and relative abundance using the formulae:

$$\text{Catch per unit effort} = \frac{\text{No. of individuals caught}}{\text{Total no. of fishing hours / total number of cast}}$$

$$\text{Relative abundance} = \frac{\text{No. of individuals i}^{\text{th}}\text{ species}}{\text{total number all species}} * 100$$

Canonical correspondence analysis (CCA) was used to evaluate the factors influencing the species abundance. Monte Carlo permutation test (1,000 random permutations) was used to determine environmental variables that significantly ($P<0.05$) explained variation in fish assemblage data sets. In addition, environmental variables that exhibited collinearity and variance inflation factors (VIF) > 10 were removed because such variables are strongly correlated with other variables and, therefore, do not make a unique contribution to the regression equation. To simplify the ordination biplot, only species with abundances more significant than five were included in the Canonical Correspondence Analysis (CCA).

Figure 6.1
Fish survey using the cast net method in the Godavari River

6.3 Fish assemblage of Godavari River

A total of 60 species of fish belonging to 11 orders and 15 families were recorded in the Godavari River with a diversity value of 1.76. (Table 6.1). Cyprinidae (n=27 species) was the most dominent family, followed by Danionidae (n=7 species), Bagridae (n=6 species), Channidae (n=3 species) and Cichilidae (n=3 species). (Figure 6.2). Of the recorded species, 53.33% (n=32) were freshwater fishes, and 46.67% (n=28) were migratory species that frequently migrate between freshwater and brackish water.

Among these 60 species, three species viz., *Oreochromis mossambicus*, *Cyprinus carpio*, and *Wallago attu* were vulnerable, and two species viz., *Ompok bimaculatus* and *Chitala chitala* were near-threatened according to the IUCN Red List of Threatened Species. Five species viz., *Cyprinus carpio*, *Hypophthalmicthys nobilis*, *Oreochromis mossambicus*, *Oreochromis niloticus*, and *Pygocentrus nattereri* were invasive to the Godavari River. Appendix 6.1 and table 6.1 and 6.2 show the fish recorded in this study of the Godavari River.

Species of conservation significance

Among the recorded fish species of Godavari, three species viz., *Cyprinus carpio*, *Wallago attu*, and *Oreochromis mossambicus*, were listed as vulnerable (VU) in IUCN Redlist of threatend species. *Oreochromis mossambicus* was observed in segment 3 of the upper zone and *Wallago attu* recorded in segments viz., 2, 5, 6, 7, 8, 9, 10, 11 and 17 of both the upper and middle zones while *Cyprinus carpio* was recorded from market in the upper zone of the Godavari river (Table 6.5).

Table 6.1 Summary of Ichthyofauna recorded in Godavari River

Details	Upper zone	Middle zone	Lower zone	Overall
Order	10	5	10	11
Family	13	8	13	15
Species Richness	40	20	40	60
Diversity (H' Index)	1.75	1.9	1.73	1.76
Native Species	36	18	39	55
Invasive Species	4	2	1	5
Freshwater Species	20	8	22	32
Freshwater & Brackish water Species	22	12	18	28
Food fish species	16	12	21	27
Ornamental fish species	6	2	6	8
Food & Ornamental fishes	8	1	5	11
Low commercial value species	6	2	4	7
Near-Threatened	1	0	1	2
Vulnerable	3	1	0	3
Least Concern	32	16	31	46
Data Deficient	1	1	1	1
Not Evaluated	1	1	1	1

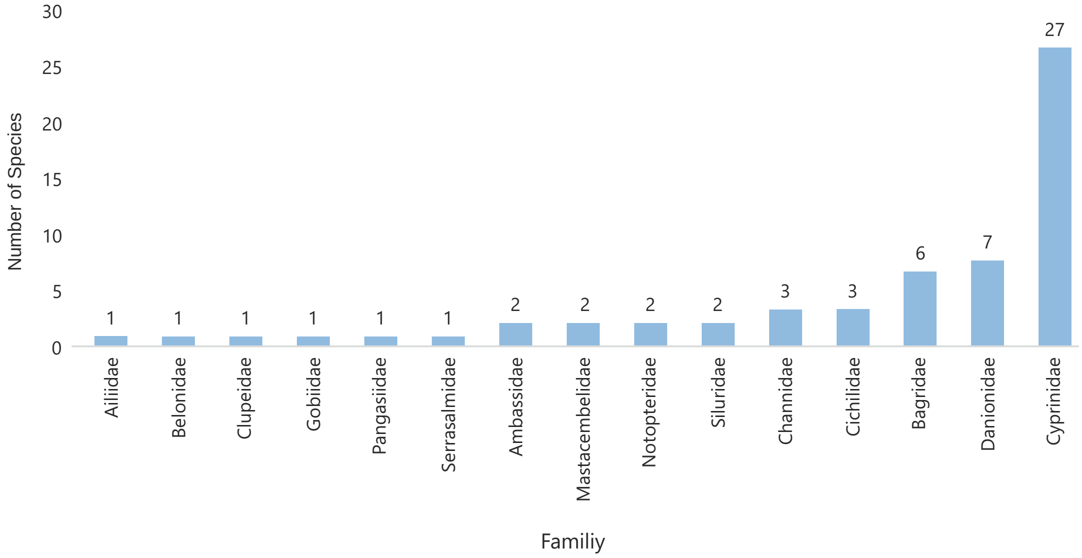


Figure 6.2 The overall family-wise richness of Ichthyofauna recorded in the Godavari River

Table 6.2 Threatened and near-threatened fish recorded in the Godavari River

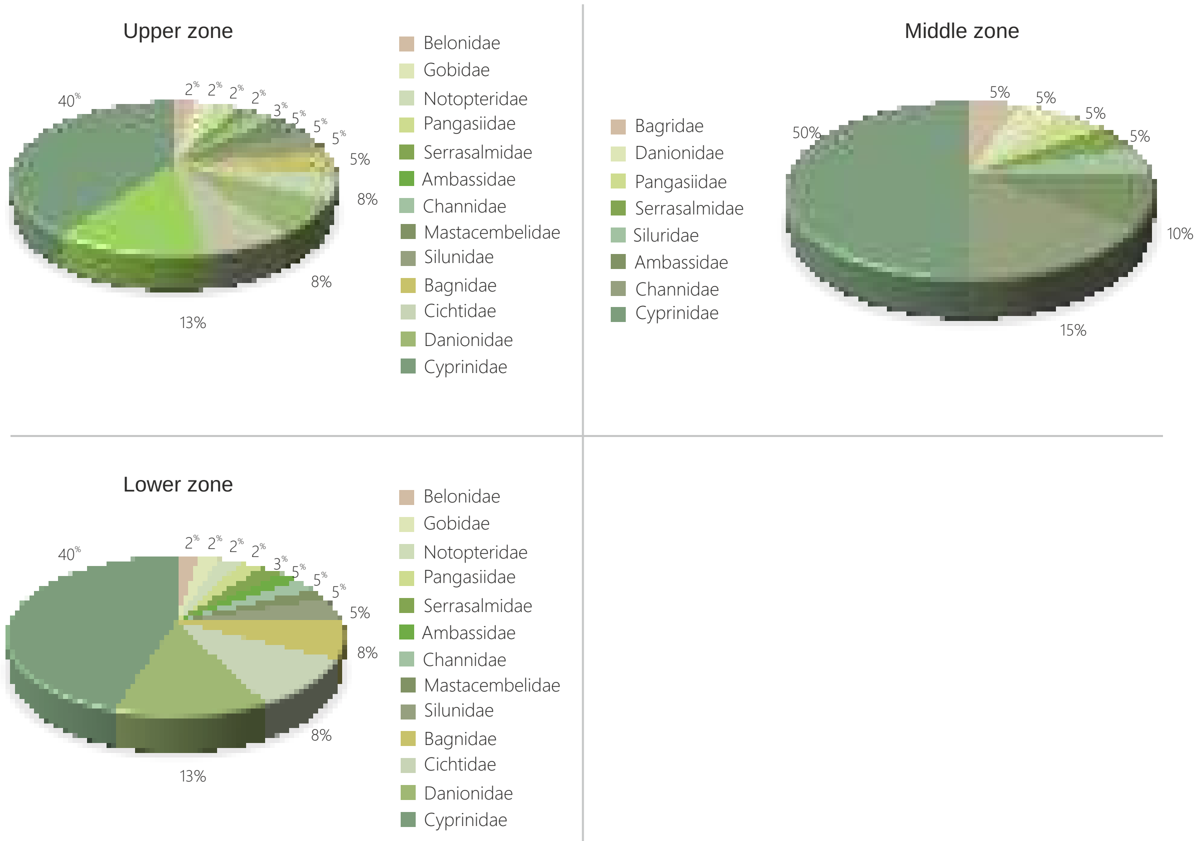
Family	Species	IUCN	Zone
Siluridae	*Wallago attu*	VU	Upper zone and middle zone
Cichilidae	*Oreochromis mossambicus*	VU	Upper zone
Cyprinidae	*Cyprinus carpio*	VU	Upper zone
Siluridae	*Ompok bimaculatus*	NT	Upper zone
Notopteridae	*Chitala chitala*	NT	Lower zone

VU: Vulnerable, NT: Near-threatened

6.3.1 Fish assemblage in various zones of the Godavari River

Fish species richness was higher in both the upper and lower zones (n=40) than in the middle zone (n=20) (Table 6.1). Family Cyprinidae was dominant in all the zones of the Godavari River (Figure 6.2, 6.3). However, the diversity of fish was higher in the middle zone (H'=1.90), followed by the upper zone (H' =1.75) and lower zone (H'= 1.73) (Table 6.1). All the vulnerable and near-threatened species were found in the upper zone and middle zone. One near-threatened species, viz., *Chitala chitala* recorded in the lower zone (Table 6.2).

Figure 6.3
Percentage of fishes in various families recorded in the different zones of the Godavari River



6.3.2 Status of economically important fishes

Analysis of the economic importance of fishes revealed a total of 27 species were food fishes; 8 were ornamental fishes, and 11 were decorative or food fishes (detail in Table 6.3). Out of the 27 food varieties of fish, 22 were in the least concern (LC) category of IUCN, and one was vulnerable. Among ornamental species, eight was least concern. Among 11 ornamental/food fishes two were vulnerable and two were near-threatened. Figure 6.4 highlights the conservation status of economically valuable fish species recorded from the Godavari River.

Figure 6.4
Status of threatened fishes of commercial importance recorded from the Godavari River

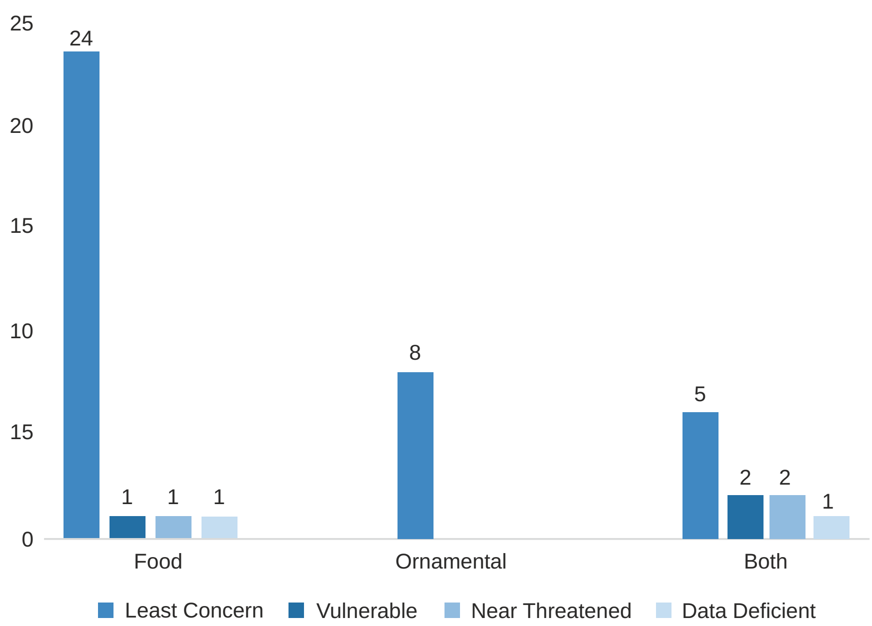


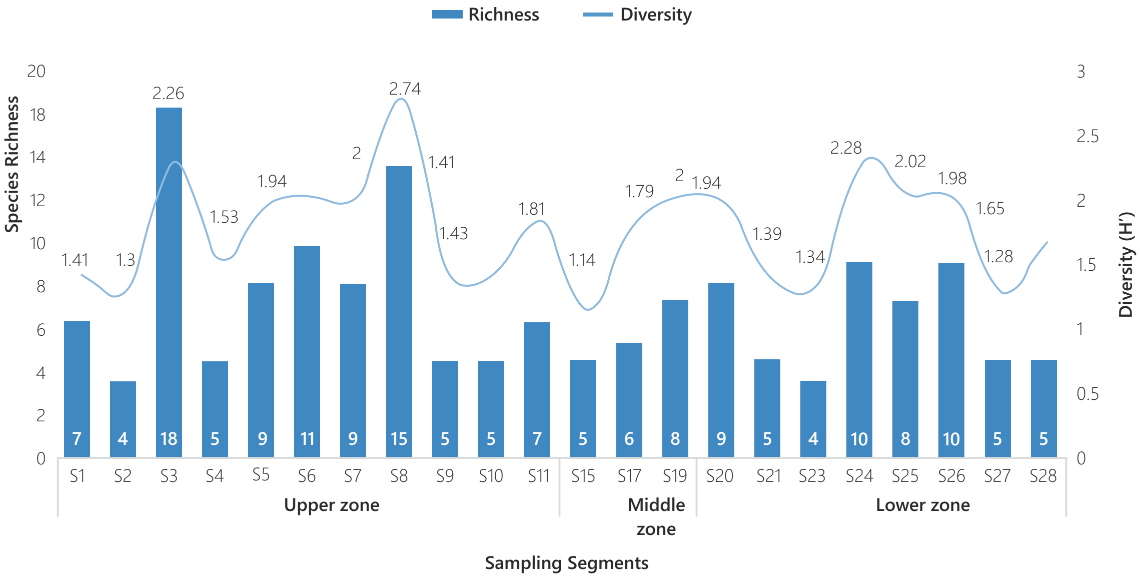
Table 6.3 Economically important fish species recorded in the Godavari River

Food	IUCN status	Ornamental	IUCN status	Ornamental/Food	IUCN status
Bangana dero	LC	*Pethia ticto*	LC	*Wallago attu*	VU
Cirrhinus mirgala	LC	*Puntius chola*	LC	*Hypophthalmichthys nobilis*	DD
Cirrrhinus reba	LC	*Puntius conchonius*	LC	*Tor sp.*	
Labeo calbasu	LC	*Puntius sophore*	LC	*Ompok bimaculatus*	NT
Labeo catla	LC	*Devario malabaricus*	LC	*Mastacembelus armatus*	LC
Labeo rohita	LC	*Devario devario*	LC	*Etroplus suratensis*	LC
Labeo bata	LC	*Laubuka laubuca*	LC	*Oreochromis mossambicus*	VU
Labeo boggut	LC	*Chanda nama*	LC	*Oreochromis niloticus*	LC
Labeo dussumieri	LC			*Chitala chitala*	NT
Labeo fimbriatus	LC			*Notopterus synurus*	LC
Osteobrama peninsularis	DD			*Glossogobius giuris*	LC
Systomus sarana	LC				
Salmostoma bacaila	LC				
Mystus cavasius	LC				
Mystus vittatus	LC				
Rita kuturnee	LC				
Rita rita	LC				
Channa punctatus	LC				
Channa marulius	LC				
Tenualosa ilisha	LC				
Cyprinus carpio	VU				
Pygocentrus nattereri	NE				
Sperata seenghala	LC				
Eutropiichthys vacha	LC				
Pangasius pangasius	LC				
Channa striatus	LC				
Xenentodon cancila	LC				

6.3.3 Richness and diversity of fish in various sampling segments

The richness of fish species ranged between 4 and 18 in the sampling segments. Maximum richness of fish species was observed at segment 3 (n=18), followed by segment 8 (n=15) and segment 6 (n=11). The lowest richness was observed in segment 23 (Figure 6.5). The overall diversity value is 1.76. The result indicates that maximum diversity was observed in Segment 8 (H' = 2.74) and lowest in Segment 15 (H' =1.147) (Figure 6.5).

Figure 6.5
Richness and diversity of fish at various sampling segments in the Godavari River



6.3.4 Abundance of Ichthyofauna

6.3.4.1 The catch per unit effort (CPUE)

The CPUE of fish in the Godavari River was 4.88 fish/hour. The CPUE value ranged between 0.50-10.63 and 0.88-4.88 fishes/hour in the upper and middle zone respectively (Figure 6.6). CPUE was maximum in sampling segment 5 (10.63 fishes/hour) and minimum in segment 1 (0.50 fishes/hour).

Chanda nama had the highest CPUE among the recorded species, followed by *Osteobrama vigorsii, Systomus sarana*, and *Puntius sophore*. In the upper zone, *Puntius sophore* had the highest CPUE (0.32 fish/hour), followed by *Chanda nama* (0.31 fish/hour) and *Oreochromis niloticus* (0.28 fish/hour). In the middle zone, *Systomus sarana* and *Osteobrama vigorsii* recorded the highest abundance (0.68 fish/gill), followed by *Mystus cavasius* (0.43 fish/ hour each). However, in the lower zone, *Osteobrama vigorsii* had the highest abundance (0.65 fish/hour).

6.3.4.2 Relative abundance

Among the recorded species of fish, *Chanda nama* had the maximum relative abundance value (RA: 12.35%), and was followed by *Osteobrama vigorsii* (RA: 8.74%) and *Systomus sarana* (RA: 8.27%) (Table 6.4). In the upper zone, *Puntius sophore* had the maximum relative abundance (11.2%), followed by *Chanda nama* (11.03 %), and *Oreochromis niloticus* (9.96 %). Five species in the upper zone show a low RA value (0.17% each – Table 6.4). In the middle zone, *Systomus sarana* and *Osteobrama vigorsii* had the highest relative abundance (19.64% each), followed by *Mystus cavasius* (12.5%). In the lower zone, *Osteobrama vigorsii* (17.5%) had the highest relative abundance, followed by *Chanda nama* (16.25%) and *Glossogobius giuris* (12.5 %). Information on the relative abundance of various fish species recorded in the Godavari River is provided in Table 6.4

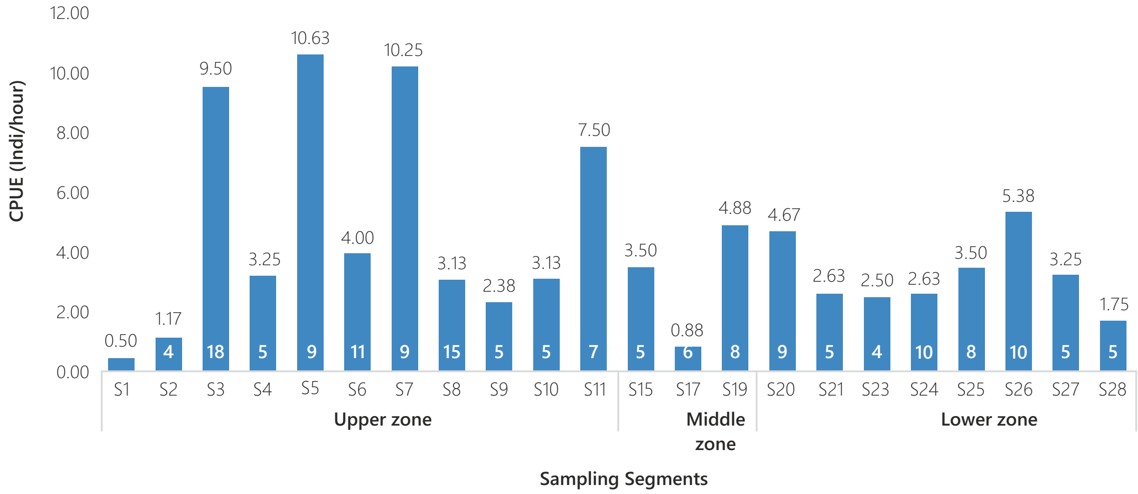
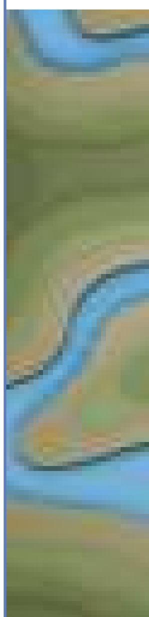


Figure 6.6 Catch per unit effort (CPUE) of fish at various sampling segments in Godavari River

Table 6.4: Relative abundance of fish in the Godavari River

Species	Upper zone		Middle zone		Lower zone		Overall abundance	Overall CPUE (Indi/hour)
	Relative abundance (%)	Catch Per Unit Effort	Relative abundance (%)	Catch Per Unit Effort	Relative abundance	Catch Per Unit Effort		
Bangana dero	1.77	0.010	0	0	0	0	1.16	0.05
Chanda nama	11.03	0.051	8.92	0.31	16.25	0.60	12.35	0.60
Chitala chitala	0	0.31	0	0	0.41	0.01	0.11	0.005
Cirrhinus reba	2.31	0	8.92	0.31	8.75	0.32	4.54	0.22
Devario malabaricus	6.76	0.06	0	0	0.83	0.03	4.66	0.22
Etroplus suratensis	0.17	0.19	0	0	0.41	0.015	0.23	0.011
Eutropiichthys vacha	0	0.005	0	0	0.83	0.03	0.23	0.011
Garra sp	0	0	0	0	2.5	0.09	0.69	0.034
Garra mullya	3.55	0	0	0	0	0	2.33	0.11
Glossogobius giuris	4.62	0.10	0	0	12.5	0.46	6.5	0.32
Labeo bata	0	0.13	0	0	0.83	0.03	0.23	0.011
Labeo boggut	0	0	0	0	1.66	0.06	0.46	0.022
Labeo calbasu	0	0	3.57	0.12	0	0	0.23	0.011
Labeo dussumieri	0	0	0	0	0.41	0.01	0.11	0.0057
Labeo fimbriatus	0	0	0	0	0.41	0.01	0.11	0.0057
Labeo rohita	2.13	0	0	0	0	0	1.39	0.06
*Labeo sp*1	0	0.06	0	0	2.91	0.06	0.81	0.022
*Labeo sp*2	0	0	0	0	1.66	0.10	0.46	0.04
Laubuka laubuca	0	0	0	0	0.41	0.01	0.11	0.0057
Macrognathus pancalus	0.17	0	0	0	0.41	0.01	0.23	0.0057
Mystus cavasius	2.49	0	12.5	0.43	5.41	0.20	3.96	0.19
Mystus sp	0.17	0.07	0	0	0	0	0.11	0.0057
Mystus vittatus	0.17	0.005	0	0	1.66	0.06	0.58	0.02



Species	Upper zone		Middle zone		Lower zone		Overall abundance	Overall CPUE (Indi/hour)
	Relative abundance (%)	Catch Per Unit Effort	Relative abundance (%)	Catch Per Unit Effort	Relative abundance	Catch Per Unit Effort		
Notopterus synurus	0.88	0.005	0	0	0	0	0.58	0.02
Ompok bimaculatus	1.60	0.02	0	0	0	0	1.04	0.05
Oreochromis mossambicus	0.711	0.04	0	0	0	0	0.46	0.02
Oreochromis niloticus	9.96	0.02	0	0	0	0	6.52	0.32
Osteobrama peninsularis	1.77	0.28	1.78	0.06	0.41	0.01	1.39	0.06
Osteobrama vigorsii	3.91	0.05	19.64	0.68	17.5	0.65	8.74	0.43
Parambassis thomassi	4.27	0.11	1.78	0.06	4.58	0.17	4.07	0.20
Pethia ticto	5.16	0.12	0	0	4.58	0.17	4.66	0.22
Puntius chola	2.49	0.14	8.92	0.31	1.66	0.06	2.68	0.13
Puntius conchonius	0.53	0.07	0	0	0	0	0.34	0.01
Puntius sophore	11.2	0.01	0	0	0	0	7.34	0.36
Rasbora dandia	3.73	0.32	0	0	0	0	2.44	0.12
Rita kuturnee	0	0.10	0	0	2.5	0.09	0.69	0.03
Rohtee ogibii	0	0	0	0	0.41	0.01	0.11	0.005
Salmostoma bacaila	3.73	0	8.92	0.31	0.41	0.01	3.14	0.155
Sperata seenghala	0	0.10	0	0	2.08	0.09	0.58	0.034
Systomus sarana	8.18	0	19.64	0.68	5.83	0.21	8.27	0.408
Tariqilabeo latius	0.17	0.23	0	0	0	0	0.11	0.005
Tor sp.	0	0.005	0	0	0.41	0.01	0.11	0.005
Wallago attu	1.42	0	1.78	0.06	0	0	1.04	0.05
Xenentodon cancila	4.09	0.04	0	0	0	0	2.68	0.13
Overall CPUE								**4.88**

6.3.5 Distribution of fishes

An assessment of the occurrence pattern of the fish species indicated that only nine species, viz., *Cirrrhinus reba, Osteobrama vigorsii, Osteobrama peninsularis, Puntius chola, Systomus sarana, Salmostoma bacaila, Mystus cavasius, Parambassis thomassi* and *Chanda nama* were recorded from upper, middle, and lower zone of the Godavari River. Additionally, seven species of fish viz., *Cirrrhinus reba, Osteobrama vigorsii, Mystus cavasius, wallago attu, Chanda nama, Glossogobius giuris*, and *Systomus sarana* showed a broad range distribution pattern and were recorded from eight or more sampling segments of the Godavari River.

A total of 15 species were restricted to the upper zone of the Godavari River (Table 6.5), among these six species viz., *Puntius conchonius, Tariqilabeo latius, Amblypharyngodon mola, Devario sp.*, *Mystus sp.*, and *Oreochromis mossambicus* showed a very narrow distribution range and were recorded from only one sampling segment of the upper zone. *Garra mullya* was recorded from only two sampling segments, and *Rasbora dandia* was recorded from three sampling segments of the upper zone of the Godavari River.

A total of 13 species were restricted to the lower zone of the Godavari River (Table 6.5), among these five species viz., *Rohtee ogilbii, Tor sp., Laubuka laubuca, Sperata seenghala, Eutropiichthys vacha*, and *Chitala chitala* showed a narrow distribution and were recorded from only one sampling segment. Two species viz., *Garra sp.* and *Rita kuturnee* were recorded from two sampling segments of the lower zone of the Godavari River.

6.4 Fish market and landing sites survey in Godavari River

A total of twelve fish species belonging to six orders and six families (*Cyprinus carpio, Cirrhinus mirgala, Hypophthalmichthys nobilis, Pangasius pangasius, Tenualosa ilisha, Pygocentrus nattereri, Labeo catla, Labeo sp., Channa marulius, Channa punctatus, Channa striatus*, and *Notopterus synurus*) were recorded from fish markets and landing sites survey along the Godavari River. Among these, three species were exotic viz., *Pygocentrus nattereri, Hypophthalmichthys nobilis*, and *Cyprinus carpio. Pygocentrus nattereri* were found in all three zones upper, middle, and lower. *Hypophthalmichthys nobilis* was found in the middle zone, while *Cyprinus carpio* was recorded only in the upper zone.

Table 6.5: Distribution of Ichthyofauna recorded in the various segments in the Godavari River

Species										Upper zone				Middle zone				Lower zone				
	1	2	3	4	5	6	7	8	9	10	11	15	17	19	20	21	23	24	25	26	27	28
Bangana dero	+	-	+	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cirrhinus reba	-	-	-	-	-	+	+	-	+	+	+	+	-	+	-	+	-	+	+	-	-	-
Garra sp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-
Garra mullya	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Labeo calbasu	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-
Labeo rohita	-	-	-	-	+	+	+	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-
Labeo bata	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Labeo boggut	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
Labeo dussumieri	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Labeo fimbriatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
*Labeo sp*1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	-	+	-	-
*Labeo sp*2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	-	-
Osteobrama vigorsii	-	-	-	-	-	-	-	+	-	-	-	+	+	+	+	-	-	-	-	+	+	+
Osteobrama peninsularis	-	-	+	-	-	-	-	+	-	-	-	+	-	+	-	-	-	+	-	-	-	-
Pethia ticto	+	-	-	+	-	+	+	-	-	-	-	-	-	-	+	-	+	+	-	-	-	-
Puntius chola	-	-	-	-	-	-	+	+	-	-	-	-	-	+	+	-	-	-	-	-	-	-
Puntius conchonius	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rohtee ogilbii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Systomus sarana	-	-	+	+	+	+	-	+	-	-	-	+	+	+	+	-	-	-	-	-	-	-
Puntius sophore	-	+	-	+	-	-	+	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-
Tariqilabeo latius	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tor sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Amblypharyngodon mola	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Species	Upper zone											Middle zone					Lower zone					
	1	2	3	4	5	6	7	8	9	10	11	15	17	19	20	21	23	24	25	26	27	28
Devario malabaricus	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Devario devario	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Devario sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Laubuka laubuca	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Rasbora dandia	+	-	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Salmostoma bacaila	-	-	+	-	-	+	-	+	-	-	-	-	+	-	-	-	-	-	-	+	-	-
Mystus cavasius	-	-	+	-	-	-	+	+	-	-	+	+	-	+	-	-	-	+	+	-	+	+
Mystus vittatus	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-
Mystus sp.	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rita kuturnee	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-
Sperata seenghala	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-
Eutropiichthys vacha	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Ompok bimaculatus	-	-	-	-	-	+	-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-
Wallago attu	-	+	-	-	+	-	+	+	+	+	+	-	+	-	-	-	-	-	-	-	-	-
Parambassis thomassi	-	-	+	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+	+	+
Chanda nama	+	-	+	-	+	+	-	+	-	-	-	-	-	+	+	+	-	+	+	-	-	-
Macrognathus pancalus	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
Etroplus suratensis	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-
Oreochromis mossambicus	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oreochromis niloticus	-	+	-	+	-	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
Chitala chitala	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Notopterus synurus	-	+	-	-	-	-	+	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-
Xenentodon cancila	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Glossogobius giuris	-	-	+	-	+	+	-	+	-	-	-	-	-	-	+	+	+	-	+	+	-	-

(+) = Presence, (-) = Absence

6.5 Endemism in the Godavari River

Twenty-three species recorded from the Godavari River during this study, showed various levels of endemism. Out of 23, three species were endemic to Peninsular India (*Garra mullya, Rita kuturnee,* and *Chitala chitala*), three were endemic to India-Sri Lanka (*Labeo dussumieri, Devario malabaricus*, and *Etroplus suratensis*) and two species are exclusively endemic to Southern India (*Osteobrama vigorsii* and *O. peninsularis*). At the same time, two were endemic to the Western Ghats (*Rohtee ogilbii* and *Parambassis thomassi*) and the rest of the 13 species were endemic to Asia (Table 6.6).

Nature of Endemism	Upper zone	Middle zone	Lower zone	Overall
Asia	8	3	7	13
Western Ghats	1	-	2	2
Peninsular India	1	-	2	3
India-Sri Lanka	2	-	3	3
Southern India	2	2	2	2

Table 6.6 Status of endemic Ichthyofauna recorded from the Godavari River

6.6 Environmental variables influencing the fish abundance

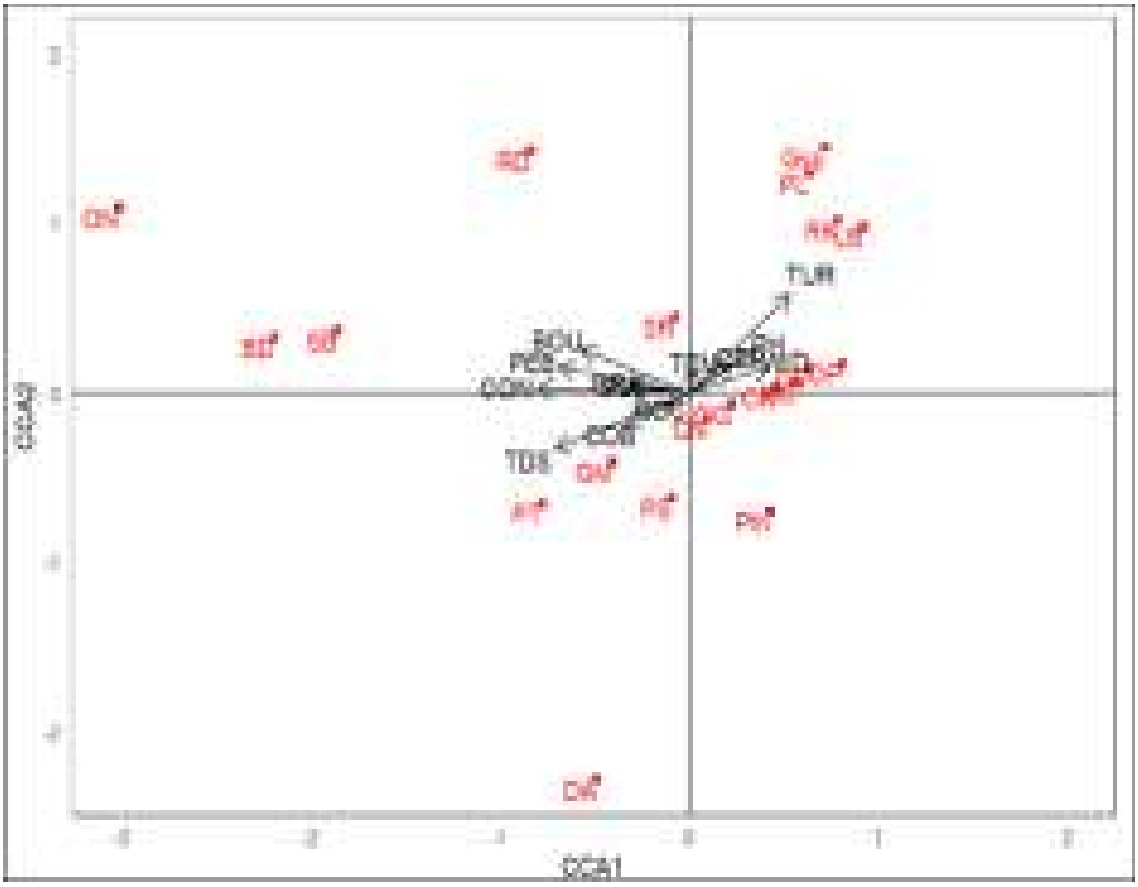
The result of CCA revealed that the total variance explained collectively by the first and second axes was 38.91%. CCA1 and CCA2 explained 22.75% and 16.15% of the variance, respectively. The first CCA ordination Axis indicated a positive association with turbidity, width, and depth with fish abundance and a negative association with conductivity and boulder and pebble substratum (Table 6.7). The second CCA ordination axis was positively associated with the TDS of water and negatively associated with fish abundance. (Table 6.7).

Rita kuturnee and *Labeo bata* were associated with high turbidity and low TDS. Whereas four species *Osteobrama vigrosii*, *Osteobrama peninsularis*, *Cirrrhinus reba* and *Mystus cavasius*, *Osteobrama peninsularis*, *Cirrrhinus reba*, and *Mystus cavasius*, were associated with larger river width, higher pH levels, greater river depth, and lower TDS. *Garra mullaya* was found in areas with a presence of cobbles, while *Pethia ticto* showed an association with high TDS (Figure 6.7).

Importance of components	Axis 1	Axis 2
Eigenvalues	0.63	0.44
Proportion Explained	0.22	0.16
Cumulative Proportion	0.22	0.38
Width	0.42	0.15
Turbidity	0.53	0.58
pH	0.34	0.24
Temperature	0.02	0.14
Conductivity	-0.80	0.02
Depth	0.23	0.17
TDS	-0.70	-0.33
Rock	-0.12	-0.07
Boulder	-0.57	0.25
Cobble	-0.34	-0.20
Pebbles	-0.688	0.15
Gravel	-0.31	0.04
Silt	-0.33	0.03

Table 6.7 Canonical correspondence analysis summary statistics for the fish and environment sampled in Godavari River

Figure 6.7: Canonical correspondence analysis plot showing a correlation between species composition and environmental variables. (BD- *Bangana dero*, CR- *Cirrrhinus reba*, Gsp- *Garra spp*, GM- *Garra mullaya*, LB- *labeo bata*, OV- *Osteobrama vigorsii*, OP- *Osteobrama peninsularis*, PT- *Pethia ticto*, PL- *Puntius chola*, SR-*systomus sarana*, PS- *Puntius sophore*, DA- *Devario malabaricus*, RD- *Rasbora dandia*, SB-*Salmostoma bacaila*, MC- *Mystus cavasius*, RK- *Rita kuturnee*, Pth- *Parambassis thomassi*, CN- *Chanda nama*, ON- *Oreochromis nilotica*, GG- *Glossogobius giuris*. WID- width, SAL- salinity, TEM- temperature, TUR- Turbidity, CON- conductivity, DEP- depth, ROC- rock bed, BOU- boulder, COB- cobbles, PEB- pebbles, SIL- Silt, GRA- Gravel.)



6.7 Habitat suitability and stretches of Conservation Priority

A total length of 902 km stretch, including 463 km in the upper zone, 181 km in the middle, and 258 km in the lower zone of the Godavari River, was found suitable for the fish (Table 6.8). Of the total suitable stretches in the Godavari River, 83 km is conserved by five protected areas located on the Godavari River (Table 6.9). Of the river stretches found suitable for fish species, a length of 225 km, including 56 km in the upper, 64 in the middle, and 106 in the lower zone, were suitable for five to seven species of fish (Table 6.8). A total of 455 km, including 231 km in the upper zone, 112 in the middle zone, and 111 km in the lower zone was suitable for three to four species of fish. Figures 6.9 to 6.11 visually illustrate the habitat suitability stretches for fishes in the Godavari River.

High-priority stretches for conservation were observed from Kumbhari to Hingani (2.6 km), Mardasgaon to Dhalegaon (10.5 km), Pimplgaon to Navghat Bridge (52 km) and Digras Chirli Bridge to Manur (14 km) in the upper zone (Table 6.10). In the middle zone, high-priority stretches for conservation were recorded from Manur to Puskar Ghat Saangvi (56 km), Mallana Swami temple to Gondeserial (6.5 km) and Medipalli Coalmine to Pushkar Ghat, Kaleshwaram (26 km). In the lower zone, Pushkar Ghat, Kaleshwaram to Singaram (77 km), Kapavaram to Chigurumamidi (32 km) and Tummileru to Trilingeswara Temple (19 km) were the conservation priority stretches (Table 6.10). Figures 6.8 to 6.11 highlight the spatial distribution of conservation priority stretches in the Godavari River.

Table 6.8: Suitable stretches for fishes in the Godavari River

River zone	Zone length (km)	Suitable 5-7 species	Suitable for 3-4 Fish species	Suitable for 1-2 fish species	Total Suitability
Upper zone	691	56	231	176	463
Middle zone	318	64	112	5	181
Lower zone	453	106	111	41	258
Total	**1462**	**225**	**455**	**222**	**902**

Table 6.9 Suitable stretches for fishes falling in various Protected Areas along Godavari River

Protected Area	Stretch of Godavari River	Suitable habitat stretches under Protected Area	Habitat suitability %
Jaikwadi WLS	74	19	25.7
Lanja Madugu Sivaram WLS	17	17	100.0
Pranahita WLS	3	0	0.0
Eturnagaram WLS	58	5	8.6
Papikonda NP	46	42	91.3
Total	**198**	**83**	**43.9**

Table 6.10: Location of high-priority stretches for conservation along Godavari River

River Zone	Stretch length (km)	GPS Location Start Location	End location	Location	Districts	States
Upper zone	2.6	74.4124 E/ 19.9112 N	74.4285 E/ 19.8867 N	Kumbhari to Hingani	Ahmad Nagar	Maharashtra
	10.5	76.2969 E/ 19.2637 N	76.3637 E/ 19.2203 N	Mardasgaon to Dhalegaon	Parbhani	Maharashtra
	52	77.0492 E/ 19.0930 N	77.3273 E/ 19.1393 N	Pimplgaon to Navghat Bridge	Nanded	Maharashtra
	14	77.7308 E/ 18.8666 N	77.8470 E/ 18.8392 N	Digras Chirli Bridge to Manur	Nanded	Maharashtra
Middle zone	56	77.8470 E/ 18.8392 N	78.2688 E/ 19.0407 N	Manur to Puskar Ghat Saangvi	Nanded & Nirmal	Maharashtra & Telangana
	6.5	19.0545 E/ 78.8780 N	19.0490 E/ 78.9244 N	Mallana Swami temple to Gondeserial	Nirmal	Telangana
	26	79.4747 E/ 18.8130 N	18.8219 E/ 79.911 N	Medipalli Coalmine to Pushkar Ghat, Kaleshwaram	Jayashankar	Telangana
Lower zone	77	18.8219 E/ 79.9114 N	18.4735 E/ 80.3812 N	Pushkar Ghat, Kaleshwaram to Singaram	Jayshankar	Telangana
	32	17.6060 E/ 81.0637 N	80.6562 E/ 18.1757 N	Kapavaram to Chigurumamidi	Mulugu	Telangana
	19	17.4627 E/ 81.4412 N	17.4163 E/ 81.5778 N	Tummileru to Trilingeswara Temple	East Godavari	Andhra Pradesh

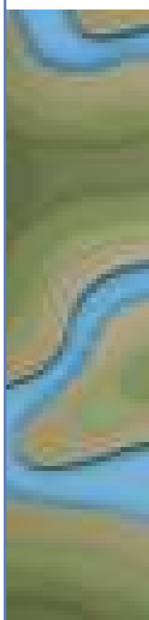


Figure 6.8
Stretches of Conservation Priority of fishes in the Godavari River

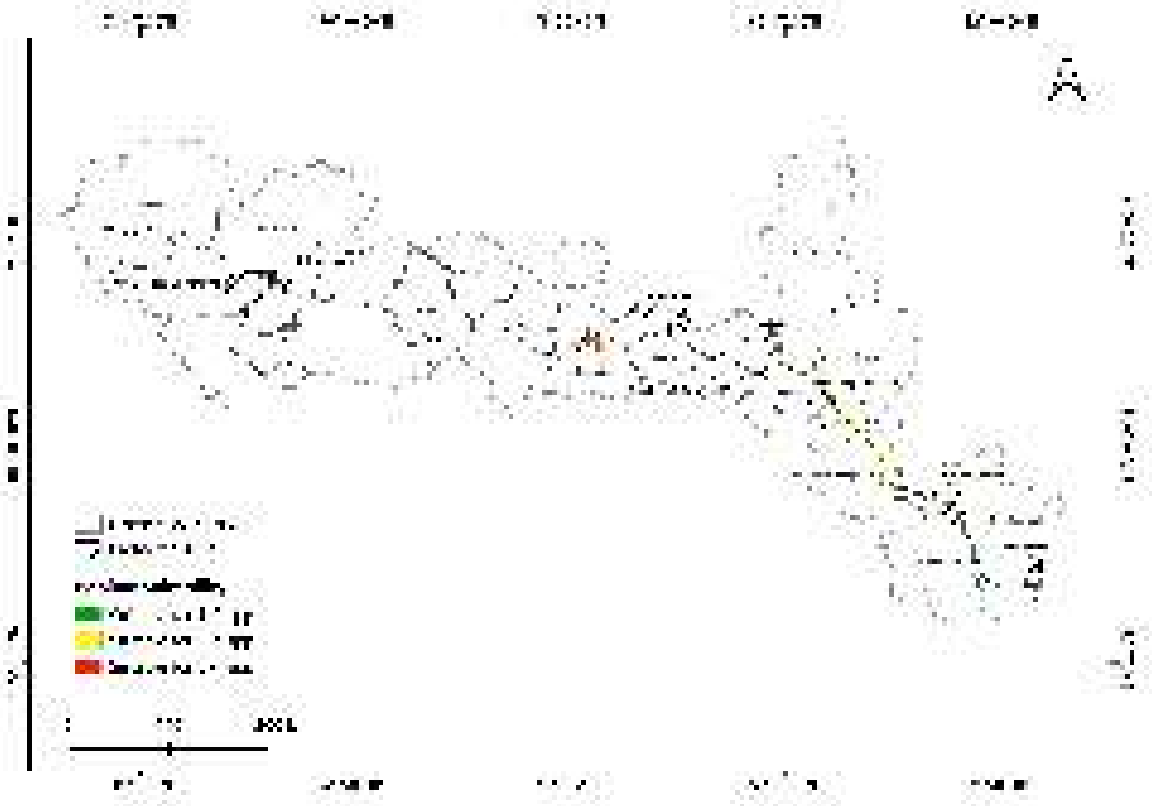
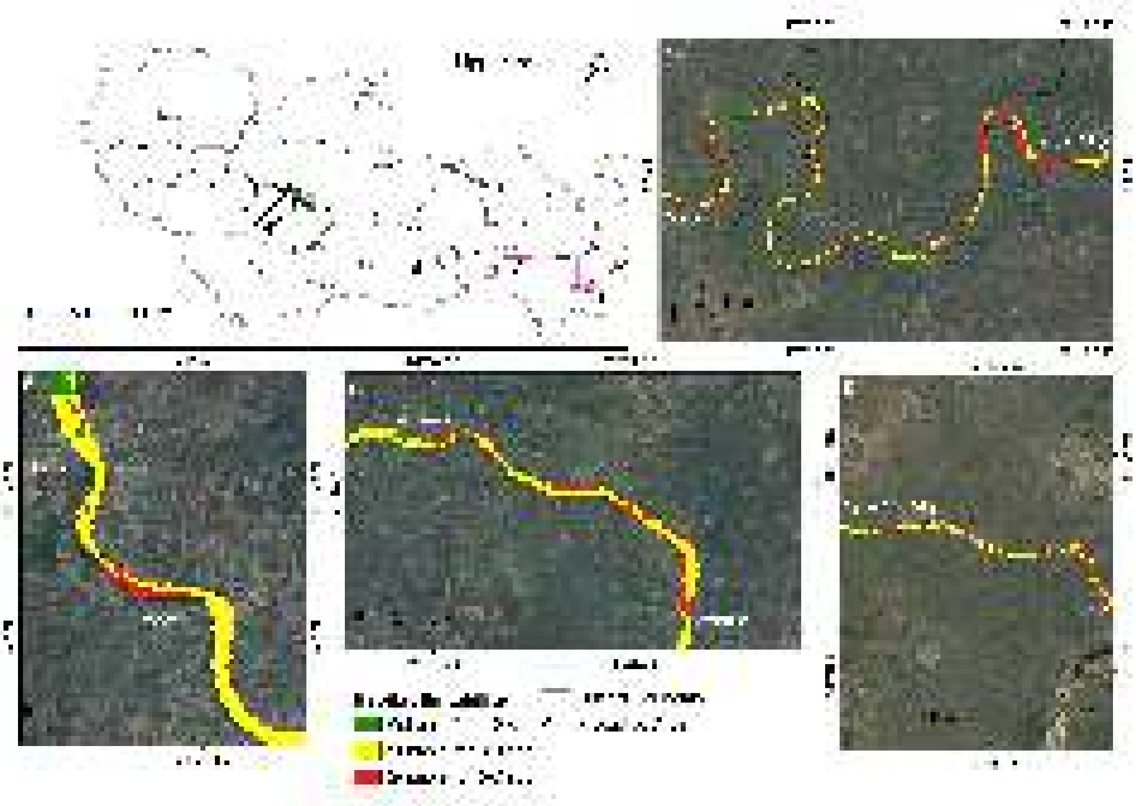


Figure 6.9
Stretches of Conservation Priority of fishes in the Upper zone of the Godavari River



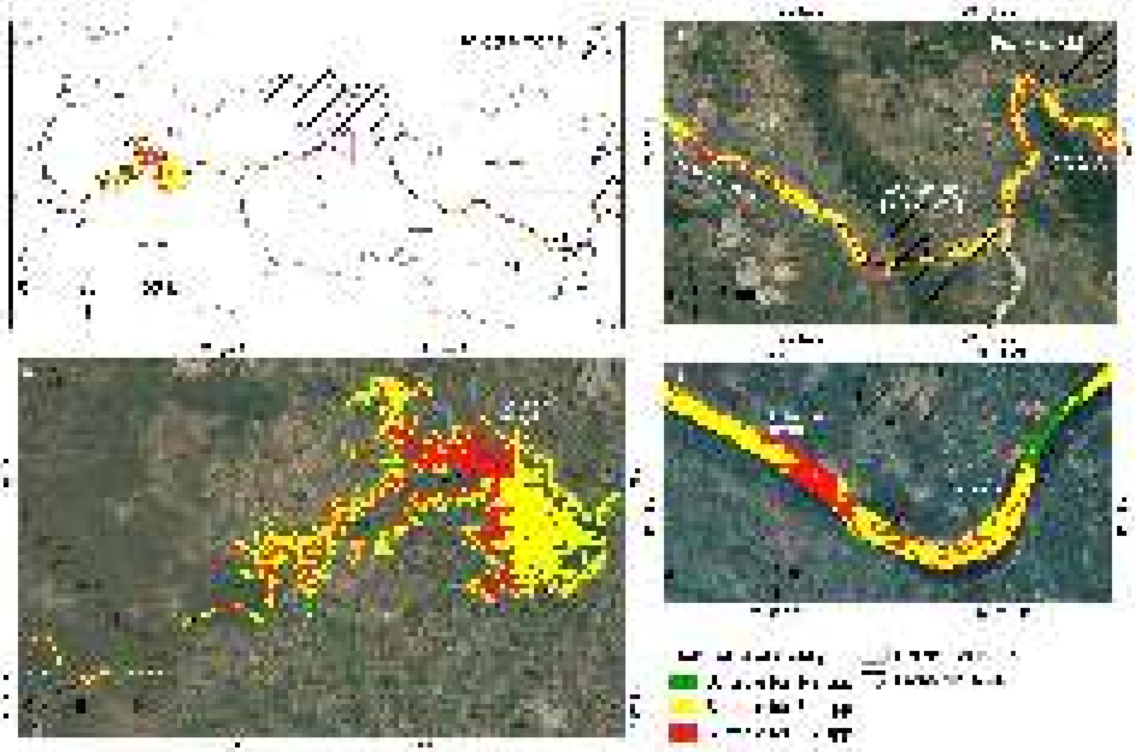


Figure 6.10 Stretches of Conservation Priority of fishes in the Middle zone of the Godavari River

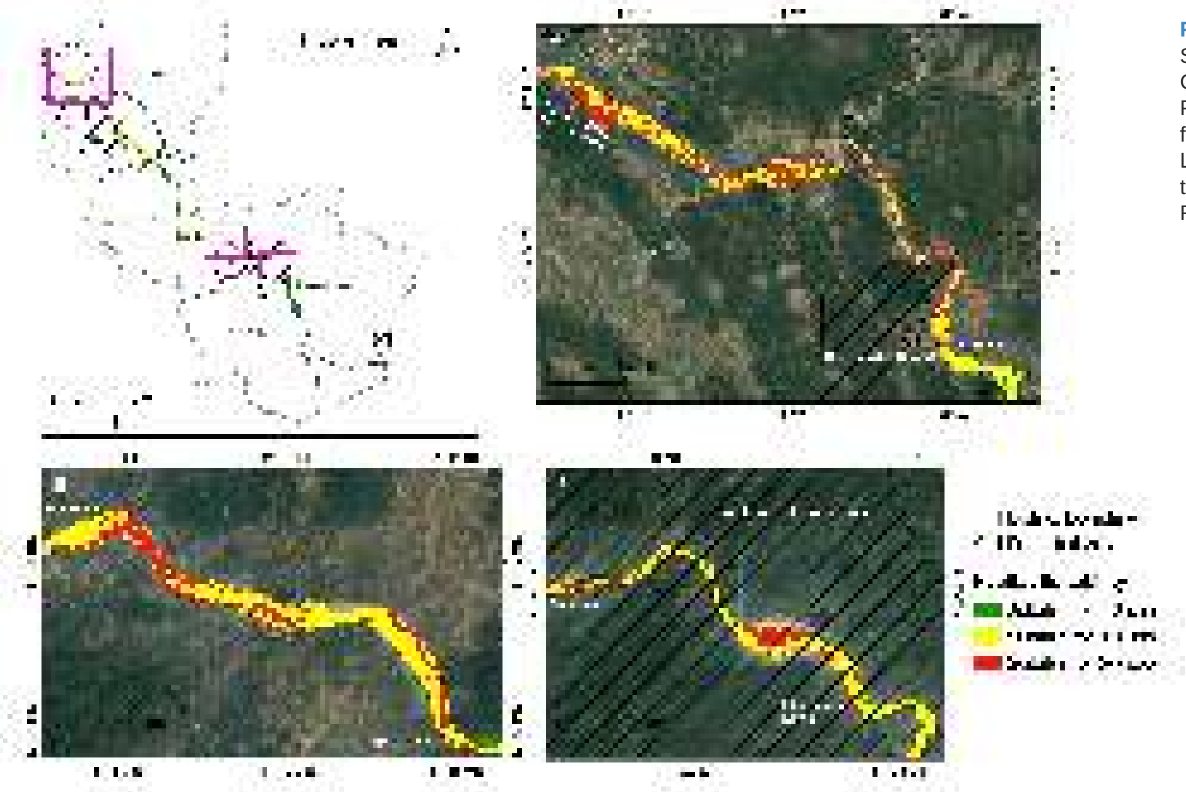


Figure 6.11 Stretches of Conservation Priority of fishes in the Lower zone of the Godavari River

6.8 Discussion

Our rapid survey revealed the presence of 60 different species of fish in the Godavari River. The recorded species represent 52.6% (Khedkar et al., 2014) and 47.2% of the overall fish species reported from the Godavari River basin (NRCD-WII, 2022). Additionally, it accounts for about 42% of the fish population of the Ganga River, 41% of that of Cauvery, 50% of Mahanadi, and 25% of the Brahmaputra River (Table 6.11). It is greater than all studies conducted in the Godavari River i.e. Pravara Sangam, Mudgal village, Dhangar Takali, Confluence of Pravara and Godavari and Vishnupuri Dam (Table 6.11). The high richness of fish recorded in the Cauvery River could be related to the comparatively higher coverage of the river length in comparison with previous studies.

The diversity of fish was lower in the lower zone than in the upper zone. The current finding aligns with the findings of Habit et al., (2006), who also highlighted the lower richness of fish in the lower zone of the Biobio River, Chile. However, our results are contradictory to various studies in river ecosystems (Almeida et al., 2004; Sarkar et al., 2010; Sarkar et al., 2012, postulating the increasing fish species richness, diversity, and abundance from upper to lower stretch of the riverine ecosystem. The observed trend in our study could be related to the high anthropogenic activities such as elevated fishing intensity, water abstraction, and pollution in the lower zone of the Godavari River (See Chapter 10).

Family Cyprinidae was the dominant family in the Godavari River. The high richness of cyprinids in the Godavari River is consistent with prior research in the Godavari River (Kalyankar et al., 2012, Balkhande and Kulkarni, 2015) and various other rivers of India viz., Barak, Periyar, Ganga, Mahanadi, Narmada (Vishwanath et al., 1998, Radhakrishnan and Kurup, 2010, Sarkar et al., 2012, Singh et al., 2013, Kakodiya and Mehra, 2018).

Fishes were recorded with an abundance value of 4.88 fish/hour in the Godavari River. This result indicated a low abundance of fish in the Godavari River. It is interesting to note that small indigenous fishes such as *Osteobrama vigorsii, Chanda nama*, and *Systomus sarana* had higher abundance in comparison with economically important food fishes such as *Mystus vitatus, Wallago attu, Labeo calbasu*, and Tor species. A similar pattern has been observed in the River Ganga, where small indigenous species were higher than species of conservation significance (Sarkar et al., 2012). Factors such as habitat degradation, overfishing and introduction of invasive species could be related to this shift in fish abundance. The dominance of small fish could have significant socioeconomic and ecological consequences. Smaller fish species generally contribute less to fisheries, potentially affecting the communities dependent on fishing. Moreover, this will impact the population of the species of conservation significance, such as *Wallago attu* and Tor species.

Our analysis revealed that the physio-chemical parameters of water such as turbidity, width, and depth, TDS of water (+ve association), conductivity, and boulder and pebble substratum (-ve association) are influencing the abundance and species richness of fish. Similar factors have also been identified in previous studies as influential in shaping fish assemblage patterns in other tropical rivers .

In the present study, it was observed that several fish species had a very narrow distribution in the Godavari River. Species such as *Puntius conchonius, Tariqilabeo latius, Amblypharyngodon mola, Devario sp., Mystus sp.*, and *Oreochromis mossambicus* were found only in one segment in upper zone, and *Rohtee ogilbii, Tor sp, Laubuka laubuca, Eutropiichthys vacha*, and *Chitala chitala* were found in one segment in lower zone. Among these, *Chitala chitala* (a near-threatened species), *Mystus sp, Eutropiichthys vacha*, were economically important fishes. Moreover, *Chitala chitala* is a near-threatened species in the IUCN Red List of Threatened Species. Therefore, habitat degradation, pollution, or overfishing could lead to the decline of these species from the Godavari River.

Our study established the occurrence of five exotic species (*Cyprinus carpio, Hypophthalmichthys nobilis, Oreochromis mossambicus, Oreochromis niloticus*, and *Pygocentrus nattereri*) in the Godavari River. This finding aligns with observation from the Godavari River basin by (Khedkar etal., 2014) who reported five exotic species (*Oreochromis mossambicus, Cyprinus carpio, Ctenopharyngodon idella, Hypophthalmichthys nobilis*, and *Hypophthalmichthys molitrix*) which include 3 species reported in the study. The occurrence of invasive species (*Cyprinus carpio, Oreochromis mossambicus*, and *Oreochromis niloticus*) in this zone is alarming as the upper zone supports maximum richness of the indigenous fishes. (Singh et al., 2013) reported the presence of *C. carpio* and *O. niloticus* impacted the native fishes of the river Ganga, particularly the major Indian carps (*Catla catla*, *Labeo rohita, Cirrhinus mrigala*).

One vulnerable (*Wallago attu*) and two near-threatened fish species (viz., *Ompok bimaculatus* and *Chitala chitala*) were recorded during the survey. *Wallago attu* was observed in the upper and middle zones (Segment 2,5,7,8,9,10,11 and 17), and near-threatened species was reported from the upper zone (segment 6,9 and 11). The presence of vulnerable and near-threatened species underscores the importance of the Godavari River for freshwater fish biodiversity. *C. chitala* typically inhabits slow-moving, deeper waters with submerged vegetation, while *O. bimaculatus* prefers faster-flowing, shallower waters with rocky substrates. Similar habitat preferences of these species were observed in the Gomti River. Protecting such critical habitats for each species within their respective zones is vital for their conservation. Table 6.11 provides the status of Ichthyofauna of the Godavari River system and larger rivers in the Indian Peninsula.

A total of 902 km stretch, that include 463 km of the upper zone, 181 km of the middle and 258 km of the lower zone of the Godavari River, was found suitable for fish. We have considered stretches containing habitats suitable for three to seven species of fish as high-priority conservation stretches for fish fauna. High-priority stretches for conservation are located from Kumbhari to Hingani (2.6 km), Mardasgaon to Dhalegaon (10.5 km), Pimplgaon to Navghat Bridge (52 km) and Digras Chirli Bridge to Manur (14 km) in the upper zone (Table 6.10). In the middle zone, high-priority stretches for conservation were from Manur to Puskar Ghat Saangvi (56 km), Mallana Swami temple to Gondeserial (6.5 km) and Medipalli Coalmine to Pushkar Ghat, Kaleshwaram (26 km). In the lower zone, Pushkar Ghat, Kaleshwaram to Singaram (77 km), Kapavaram to Chigurumamidi (32 km), and Tummileru to Trilingeswara Temple (19 km) were the high-priority stretches. Of the total suitable stretches in Godavari River, 117 km is protected by six protected areas located on the Godavari River. Therefore, the remaining length of the high-priority stretches should be brought under the purview of the Wildlife (Protection) Act, 1972, for the long-term conservation of fish fauna in the Godavari River. In conclusion, this study enriches our understanding of the Godavari River's fish ecology and provides actionable insights for conservation practitioners.

Table 6.11 Status of Ichthyofauna of the Godavari River system and larger rivers in the Indian Peninsula

Study area	Richness	Reference
Vishnupuri Dam, Godavari	21	Shillewar and Totawar, (2017)
Dhangar Takali, Godavari	18	Balkhande and Kulkarni, (2015)
Confluence of Pravara and Godavari	21	Khobragade, (2016)
Pravara Sangam, Godavari	41	Shinde et al., (2009)
Mudgal village, Godavari	26	Rankhamb, (2011)
Godavari basin	114	Khedkar et al., (2014)
Sironcha, Godavari	37	Sheikh, (2014)
Northeastern Godavari basin	47	Heda, (2009)
Western ghats	287	Gopalakrishnan and Ponniah, (2000)
Larger rivers of the Indian Peninsula		
Ganga River	143	Sarkar et al., (2012)
Cauvery River	146	Koushlesh et al., (2021)
Mahanadi River	119	Kumar, (2014)

References

Almeida O, Lorenzen K and McGrath D (2004) The commercial fishing sector in the regional economy of the Brazilian Amazon. In R. Welcomme and T. Petr, (eds). Proceedings of the second international symposium on the management of large rivers for fisheries, volume 2. Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific, Bangkok, Thailand.pp. 15- 24.

Authman MM, Zaki MS, Khallaf EA and Abbas HH (2015) Use of fish as bio-indicator of the effects of heavy metals pollution. Journal of Aquaculture Research & Development 6(4), 1-13.

Balkhande J and Kulkarni A (2015) Studies of ichthyofaunal diversity of Godavari River at dhangar takli tq purna dist., Parbhani, Maharashtra, India. International journal of animal biology 1(5), 187-189.

Central Water Commission (2012) Integrated hydrological data book. New Delhi, 1-680.

Dubey VK, Sarkar UK, Pandey A, Sani R and Lakra WS (2012) The influence of habitat on the spatial variation in fish assemblage composition in an unimpacted tropical River of Ganga basin, India. Aquatic Ecology 46, 165-174.

Dwivedi A, Mishra A, Mayank P and Tiwari A (2016) Persistence and structure of the fish assemblage from the Ganga river (Kanpur to Varanasi section), India. Journal of Geography and Natural Disasters 6(159), 2167-0587.1000159.

Galib SM (2015) Fish fauna of the Brahmaputra River, Bangladesh: richness, threats and conservation needs. Journal of fisheries. 3(3), 285-292.

Ishwar BG and Zainab JM (2011) impact of industrial polltuion on Godavari river water with respect to fluctuation in Co2 and PH. Indian journal of applied research. 4, 190-191

Gopal V, Parvathy S and Balasubramanian P (1997) Effect of heavy metals on the blood protein biochemistry of the fish Cyprinus carpio and its use as a bio-indicator of pollution stress. Environmental monitoring and assessment 48, 117-124.

Gopalakrishnan A and Ponniah A (2000) Cultivable, ornamental, sport and food fishes endemic to peninsular India with special reference to Western Ghats. Endemic Fish Diversity of Western Ghats, NBFGR-NATP Publication. National Bureau of Fish Genetic Resources, Lucknow, UP, India. pp, 13-32.

Habit E, Belk MC, Cary Tuckfield R and Parra O (2006) Response of the fish community to human?induced changes in the Biobío River in Chile. Freshwater biology 51(1), 1-11.

Heda NK (2009) Fish diversity studies of two rivers of the northeastern Godavari basin, India. Journal of Threatened Taxa, 514-518.

Indian Express (2018) Asthma patients, now you can swallow this 'fish prasadam' to cure the disease.

Jayaram KC (2010) The Freshwater Fishes of the Indian Region (Revised second edition). Delhi, Narendra Publishing House, New Delhi, India.

Johnson J, Parmar R, Ramesh K, Sen S and Murthy RS (2012) Fish diversity and assemblage structure in Ken River of Panna landscape, central India. Journal of Threatened Taxa, 3161-3172.

Kakodiya SK and Mehra S (2018) Fish Diversity of Narmada River at Hoshangabad, Madhya Pradesh. International Journal of Research and Analytical Reviews 5, 28-32.

Kalyankar V, Nalage D, Dhondage T, Akhade S and Jamdar S (2012) Study of fish biodiversity from lower Dudhana Project at Parbhani District, India. World Journal of Zoology 7(4), 320-322.

Kelleher K, Westlund L, Hoshino E, Mills D, Willmann R, de Graaf G and Brummett R (2012) Hidden harvest: The global contribution of capture fisheries. Worldbank; WorldFish.

Kharat S, Dahanukar N, Raut R and Mahabaleshwarkar M (2003) Long-term changes in freshwater fish species composition in North Western Ghats, Pune District. Current Science, 816-820.

Khedkar GD, Lutzky S, Rathod S, Kalyankar A and David L (2014) A dual role of dams in fragmentation and support of fish diversity across the Godavari River basin in India. Ecohydrology 7(6), 1560-1573.

Khobragade B (2016) Ichthyofaunal diversity at the confluence of Pravara and Godavari Rivers (MS) India.

Khoshnood Z (2017) Histopathological alterations in the digestive system of Rutilus frisii kutum fry after exposure to atrazine herbicide. Romanian Journal of Biology 62(1-2), 73-86.

Koushlesh S, Sajina A and Roshith C (2021) Ichthyofaunal diversity of the major Indian rivers: A review. J. Inland Fish. Soc. India 53(1&2), 22-35.

Krishna RR, Rao KVP and Reddy DM (2011) The princess of aquaculture and the plights of the fish farmers. Aquaculture Asia Magazine 16(2), 12-16.

Kroger RL (1973) Biological effects of fluctuating water levels in the Snake River, Grand Teton National Park, Wyoming. The American Midland Naturalist 89, 478-481.

Kromhout D, Yasuda S, Geleijnse JM and Shimokawa H (2012) Fish oil and omega-3 fatty acids in cardiovascular disease: do they really work?. European heart journal 33(4), 436-443.

Kumar ST (2014) Fish diversity in selected stretch of the River Mahanadi in Odisha and the livelihood of inhabiting fisher community. International Research Journal of Biological Sciences 3(8), 98-104.

Lynch AJ, Cooke SJ, Deines AM, Bower SD, Bunnell DB, Cowx IG, Nguyen VM, Nohner J, Phouthavong K, Riley B and Rogers MW (2016)

The social, economic, and environmental importance of inland fish and fisheries. Environmental reviews 24(2), 115-121.

Nautiyal P (2005) Taxonomic richness in the fish fauna of the Himalaya, Central Highlands and Western Ghats (Indian Subcontinent). International Journal of Ecology and Environmental Sciences 31(2), 73-92.

NRCD- WII (2022) Godavari River Godavari scape River: Ecological status and trends. Ganga Aqua life Conservation Monitoring Centre, Wildlife Institute of India, Dehradun. Uttarakhand, India. Pp 141.

Prasad H, Bhanu Murty P, Sanyasi Rao M and Duvvuru R (2019) A Study on Assessment of Pollution in Godavari Estuary East Coast of India by Using Trace Metals Concentration in the Sediments. In Proceedings of International Conference on Remote Sensing for Disaster Management. 439-453.

Prasad KK, Younus M and Srinivasulu C (2020) Occurrence of Corica soborna Hamilton, 1822 (Clupeiformes: Clupeidae) in the Godavari basin, India. Journal of Threatened Taxa 12, 17361-17365.

Radhakrishnan KV and Kurup BM (2010) Ichthyodiversity of Periyar Tiger Reserve, Kerala, India. Journal of Threatened Taxa 1192-1198.

Rankhamb S (2011) Ichthyofaunal Diversity of Godavari River at Mudgal Tq. Pathri, Dist. Parbhani. Recent Research in Science and Technology 3(12).

Saad D, Chauke P, Cukrowska E, Richards H, Nikiema J, Chimuka L and Tutu H (2022) First biomonitoring of microplastic pollution in the Vaal river using Carp fish (*Cyprinus carpio*)"as a bio-indicator". Science of the Total Environment 836, 155623.

Sarkar U, Gupta B and Lakra W (2010) Biodiversity, ecohydrology, threat status and conservation priority of the freshwater fishes of river Gomti, a tributary of river Ganga (India). The Environmentalist 30, 3-17.

Sarkar U, Pathak A, Sinha R, Sivakumar K, Pandian A, Pandey A, Dubey V and Lakra W (2012) Freshwater fish biodiversity in the River Ganga (India): changing pattern, threats and conservation perspectives. Reviews in Fish Biology and Fisheries 22, 251-272.

Sarkar UK, Pathak AK, Tyagi LK, Srivastava SM, Singh SK and Dubey VK (2013) Biodiversity of freshwater fish of a protected river in India: comparison with unprotected habitat. International Journal of Tropical Biology and Conservation 61(1), 161-172.

Sarkar UK, Sharma J and Mahapatra BK (2015) A review on the fish communities in the Indian reservoirs and enhancement of fisheries and aquatic environment. Journal of Aquaculture Research and Development 6(1), 297.

Sarkar U, Singh A and Jena J (2011) Biodiversity of the freshwater fishes in the protected forest areas of Uttar Pradesh and its significance in management of riverine fish diversity. In: Proceeding of national conference on forest biodiversity: earth's living treasure. Uttar Pradesh State Biodiversity Board, Lucknow.

Sarkar UK and Bain MB (2007) Priority habitats for the conservation of large river fish in the Ganges river basin. Aquatic Conservation: Marine and Freshwater Ecosystems 17(4), 349-359.

Sheikh S (2014) Studies on Ichthyofaunal diversity of Pranhita River, Sironcha, Dist: Gadchiroli, Maharashtra, India. International Journal of Fisheries and Aquatic Studies 1(5), 144-147.

Shillewar K and Totawar D (2017) Fresh water fish fauna of Vishnupuri dam, Nanded, Maharashtra India. International Journal of Life Sciences 5(2), 283-285.

Shinde S, Pathan T, Raut K, Bhandare R and Sonawane D (2009) Fish Biodiversity of Pravara River at Pravara Sangam District Ahmednagar,(MS) India. World Journal of Zoology 4(3), 176-179.

Shukla R and Bhat A (2018) Nestedness patterns and dispersal dynamics in tropical central Indian stream fish metacommunities. Freshwater Science 37(1), 147-158.

Singh AK and Lakra WS (2006) Alien fish species in India: Impact and emerging scenario.

Singh A and Lakra W (2011) Ecological impacts of exotic fish species in India. Aquaculture Asia 16(2), 23-25. Journal of Ecophysiology and Occupational Health 6(3), 165-174.

Singh AK, Pathak AK and Lakra WS (2010) Invasion of an exotic fish-common carp, Cyprinus carpio L.(Actinopterygii: Cypriniformes: Cyprinidae) in the Ganga River, India and its impacts. Acta Ichthyologica et Piscatoria 40(1), 11-19.

Singh AK, Kumar D, Srivastava SC, Ansari A, Jena JK and Sarkar UK (2013) Invasion and impacts of alien fish species in the Ganga River, India. Aquatic Ecosystem Health & Management 16(4), 408-414.

Singh TK, Guru BC and Swain SK (2013) Review of the Research on the Fish Diversity in the River Mahanadi and Identifying the Probable Potential Ornamental Fishes among them with reference to threats and conservation measures. International Science Community Association Research Journal of Animal, Veterinary and Fishery Sciences 1(3), 16-24.

Sugunan V (2002) Clarias gariepinus (African catfish) gravitates into River Yamuna, Sutlej, Godavari: Angst comes true. Fishing Chimes 22, 50-52.

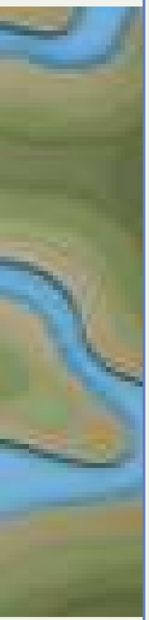
Tarur NK (2018) Community ecology of metazoan parasites of freshwater fishes of river Godavari, Rajahmundry, Andhra Pradesh, India. International Journal of Current Research in Life Sciences 7(04), 1746-1761.

Ter Braak CJ and Smilauer P (2002) CANOCO reference manual and CanoDraw for Windows user's guide: software for canonical community ordination (version 4.5). www. canoco. com.

Vishwanath W, Manojkumar W, Kosygin L and Selim KS (1998) Biodiversity of freshwater fishes of Manipur, India. Italian Journal of Zoology 65(S1), 321-324.

Wu H, Chen J, Xu J, Zeng G, Sang L, Liu Q, Yin Z, Dai J, Yin D, Liang J and Ye S (2019) Effects of dam construction on biodiversity: A review. Journal of cleaner production 221, 480-489.

Zohary T and Ostrovsky I (2011) Ecological impacts of excessive water level fluctuations in stratified freshwater lakes. Inland waters 1(1), 47-59.



07

HERPETOFAUNA

07 HERPETOFAUNA

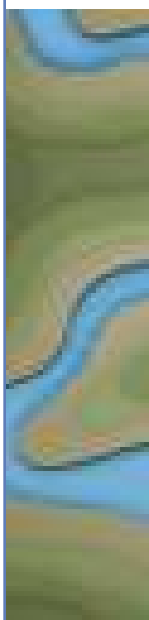
Abstract

Herpetofauna are vital components of the ecosystem as they facilitate energy flow across trophic levels, serve as both prey and predators and act as a vital indicator of ecological health. Even then studies on herpetofauna in the Godavari River are restricted mainly to sighting records. We assess the status and distribution of amphibians and reptiles in the Godavari River employing Visual Encounter Survey (VES). A total of 17 species of herpetofauna, which include 12 species of anurans and five species of reptiles, were recorded in the Godavari River. Amphibians and reptiles were recorded at a diversity of 1.79 and 1.61, respectively. Four amphibian species of (33%) and all the reptilian species had very narrow distribution. Owing to such a scanty information on herpetofauna, there is a need for continuous monitoring and community-based conservation efforts for the conservation of herpetofauna in the Godavari River.

7.1 Introduction

Herpetofauna represented by amphibians and reptiles, are crucial in connecting aquatic and terrestrial ecosystems (Valencia-Aguilar et al., 2013). This group is essential for facilitating energy flow across trophic levels, serving as prey and predator, and acting as a vital indicator of ecological health. They are important components of food chain, serve to control insect pests, and are good ecological indicators. A decline in their populations often signals habitat deterioration (Daniels et al., 2005; Frauendorf et al., 2013). Many species contribute to the stabilization of water quality in freshwater bodies like lakes, ponds, and streams. Amphibians, in particular, have gained significant attention as model organisms for studying environmental and climate change. Occupying multiple trophic levels, the unique ability of herpetofauna to thrive on low energy sources and convert them to higher trophic levels underscores their importance in conservation (Hopkins and Brodie 2015). In addition, the potential for ecotourism involving herpetofauna holds substantial promise, not only as a livelihood source for communities residing near riverine ecosystems but also as a tool for conserving the Riverscape (Loubser et al., 2001; Riyanto et al., 2019).

Indian herpetofauna is poorly studied, with few detailed comprehensive works on their taxonomy, biology, ecology, distribution, and conservation. The river Godavari is one of the



top rivers in India and comprises diverse flora and fauna. Despite the various studies conducted on the herpetofauna in this basin, a systematic and comprehensive study of the Godavari River is still lacking. Therefore, there is a critical need for studies to assess the status of herpetofauna in the Godavari River comprehensively. This chapter highlights the status, distribution, and habitat use of amphibians and reptiles inhabiting the Godavari River.

7.2 Methods of Assessment

7.2.1 Amphibians

The status of the amphibians in the Godavari River and adjoining areas was assessed by Visual Encounter Survey Method following Crump et al., (1994) and Khatiwada et al. (2019). In each segment, a total of three linear transects (1 km each) were walked transected at slow pace, exploring streams, pools, ponds, forest patch for one hour during morning and nights hours (Figure 7.1). The night survey was conducted using powerful flashlights and headlamps, while the weather data was collected using Kestrel 5200 Professional Environmental meter. Diverse habitats were searched to locate various groups of amphibians such as tree frogs, burrowing frogs and stream-dwelling frogs. During each sampling in various habitats, data on species, abundance, along with micro-habitat parameters such as ambient temperature, humidity, substrate characteristics (muddy, rocky, dry leaves), and ground cover were recorded. Ground cover was determined by employing the point intercept method. Each species was photographed for identification. Tissue samples of some unidentified individuals were collected and preserved in molecular-grade ethanol.

The abundance of various amphibians was assessed based on the encounter rate and relative abundance. All individual sightings of the amphibians were pooled and ranked according to the following abundance categories rare (1-5 sightings), common (6-25 sightings), abundant (26-50 sightings), and very abundant (>50 sightings).

7.2.2 Reptiles

Reptiles, particularly snakes and lizards, were assessed in the Godavari region using the visual encounter method. Additionally, opportunistic sightings were also recorded. Transects traversed diverse habitats (primary forest, secondary forest, human habitation, agriculture) along the main channel of the river during the days (0800 -1100) and nights (0600-0900). Reptiles were searched beneath the rock, litter, and wood logs. For each reptile sightings, data on species, abundance, and micro-habitat parameters such as ambient temperature, humidity, substrate characteristics (muddy, rocky, dry leaves), and ground cover were recorded. Each species was photographed for identification. Tissue samples of some unidentified individuals were collected and preserved in molecular grade ethanol.

The abundance of various species of reptiles was assessed based on the number of individual sighted. All individual sighted were pooled and ranked according to the following abundance categories: rare (1-5 individuals), common (6-25 individuals), abundant (26-50 individuals), and very abundant (>50 individuals).

Figure 7.1 Amphibian survey using visual encounter survey in the Godavari River

7.3 Herpetofauna in Godavari

A total of 17 species, belonging to seven families (5 amphibians & 2 reptiles) were recorded in the Godavari Riverscape. These included 12 species of anurans and 5 species of reptiles (Figure 7.2, 7.3 & 7.5).

7.3.1 Amphibians of Godavari Basin

A total of 12 species of amphibians belonging to 5 families and a single order (Anura), were encountered during the survey within the state of Maharashtra in Godavari River, with a diversity of H=1.79. The dominant family was Dicroglossidae (n=5), followed by Microhylidae (n=3) and Bufonidae (n=2). Both Rhacophoridae and Ranidae reported the least number of species (n=1) (Figure 7.4).

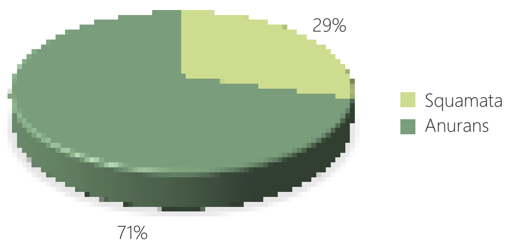


Figure 7.2: Proportion of various herpetofauna groups recorded in the Godavari River

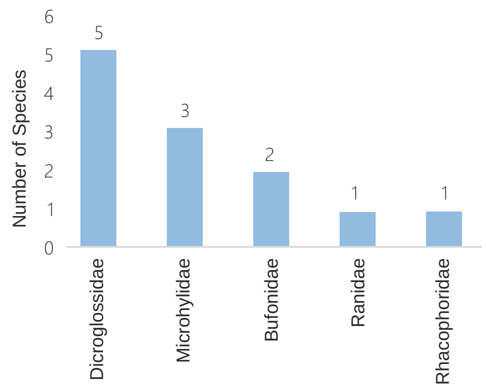


Figure 7.3 Number of species in various families of amphibians recorded in the Godavari River

7.3.1.1 Richness and diversity of Amphibians across various segments

The species richness across the segments within Maharashtra region in the Godavari River ranged from a minimum of 1 to a maximum of 8. Segment 14 had the maximum richness (8 species), and Segment 6 had the least richness (one species) (Figure 7.4).

7.3.1.2 Distribution of Amphibian species

The analysis shows that *Duttaphrynus melanostictus* was the most widely distributed species across almost all the segments, while four species viz., *Duttaphrynus stomaticus, Uperodon variegatus, Uperodon taprobanicus, Euphlyctis* cf. *jaladhara* were sparsely distributed found only in a single location from Godavari River (Table 7.1)

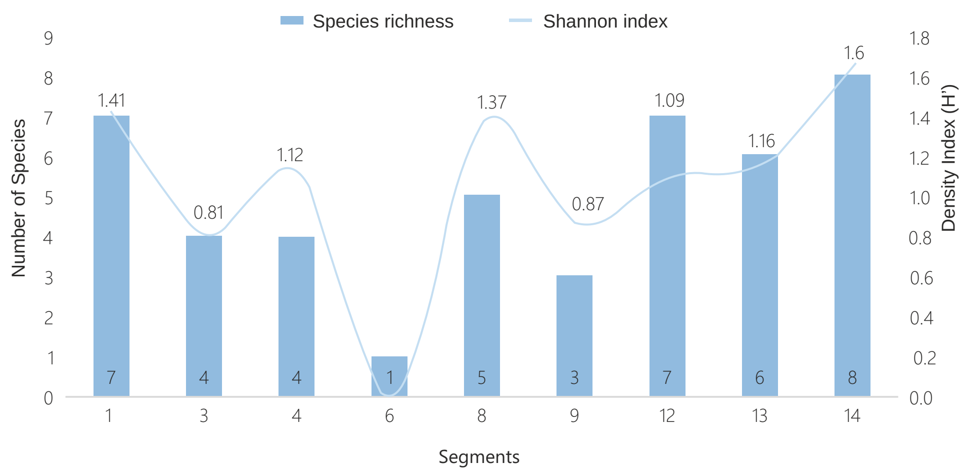


Figure 7.4 Richness and diversity of amphibians at various sampling segments in the Godavari River

Table 7.1 Distribution of amphibians in the Godavari River

Species	S1	S3	S4	S6	S8	S9	S12	S13	S14
Duttaphrynus melanostictus	+	+	+	-	+	+	+	+	+
Duttaphrynus stomaticus	+	-	-	-	-	-	-	-	-
Microhyla nilphamariensis	+	+	+	-	-	-	+	+	+
Uperodon variegatus	-	-	-	-	-	-	-	-	+
Uperodon taprobanicus	-	-	-	-	-	-	-	-	+
Minervarya cf. syhadrensis	-	-	+	-	+	+	+	+	+
Minervarya cf. rufescens	+	+	-	-	-	-	+	+	-
Hoplobatrachus tigerinus	+	+	-	+	+	-	-	-	+
Euphlyctis cyanophlyctis	+	-	+	-	-	+	+	-	+
Euphlyctis cf. jaladhara	+	-	-	-	-	-	-	-	-
Sphaerotheca maskeyi	-	-	-	-	+	-	+	+	+
Polypedates maculatus	-	-	-	-	+	-	+	+	-

The characteristics and richness status of each Amphibia family are detailed below.

Bufonidae

The amphibians in this family are typically distinguished by their dry and warty skin. Referred to as true toads, these species predominantly inhabit terrestrial environments, venturing into water bodies solely during their breeding seasons. They are found throughout India.

Two species, namely *Duttaphrynus melanostictus* and *Duttaphrynus stomaticus*, were encountered in the survey along the Godavari River. Both share the characteristic parotid glands located behind the eye. However, *D. stomaticus* sets itself apart from *D. melanostictus* by lacking cranial ridges on its head and being comparatively smaller in size.

Microhylidae

This species group exhibits a broad geographical distribution and is popularly referred to as narrow-mouthed frogs. Typically, these frogs are small to medium-sized and adopt a terrestrial or arboreal lifestyle. In the Indian context, the species in this group are mainly fossorial, spending much of their time underground and emerging above the ground only during the monsoon season for breeding purposes.

Three species viz., *Microhyla nilphamariensis*, *Uperodon variegatus*, and *Uperodon taprobanicus* belonging to two genera viz., Microhyla and Uperodon were encountered during the survey. *Microhyla nilphamariensisis* a small-sized frog (17.5mm), differing from its conspecifics in having a reduced webbing between its toes and a dorsolateral band skin fold which starts from the tip of the snout and extends till the groin on either side (Garg et al., 2018). *Uperodon variegatus* is a small-sized frog (SVL 29.8mm) and differs from its congeners in having distinct blotches or spots on the dorsal side with a whitish to off-white ventral side (Garg et al., 2018). *Uperodon taprobanicus* is a large frog (SVL 54 mm), that differs from its congeners in having the presence of two well-developed neopalatinal ridges, and light to dark grey dorsum with red or orange blotches (Garg et al., 2018).

Dicroglossidae

Widely found in tropical and subtropical regions, this amphibian family is commonly referred to as fork-tongued frogs, typically characterized by a medium to large body size.

Six species viz., *Minervarya cf. syhadrensis, Minervarya cf. rufescens, Hoplobatrachus tigerinus, Euphlyctis cyanophlyctis; Euphlyctis cf. jaldhara* and *Sphaerotheca maskeyi* belonging to four genera viz., *Minervarya, Hoplobatrachus, Euphlyctis*, and *Sphaerotheca* were encountered during the survey. *Minervarya syhadrensis* is a small-sized frog (SVL 22mm) that differs from its congeners in having a smaller adult-size, along with the dorsal side having the presence of longitudinal folds and lateral line absent in adults. *Minervarya rufescens* is a medium-sized frog (SVL 45 mm), differing from its congeners in having a blackish dorsum with red markings

(Dubois et al., 2001). The genus *Euphlyctis* is recognizable by the fully webbed toes and eyes positioned on the top of the head. The species encountered in this genus, were *Euphlyctis cf. jaldhara* and *Euphlyctis cyanophlyctis*. The distinguishing characters are the smaller adult size of the latter (SVL=58.9mm) compared to the former (SVL=62.1mm). Additionally, *Euphlyctis jaldhara* lacks porous warts on the flanks, whereas *Euphlyctis cyanophlyctis* features a single row of porous warts on its flanks (Dinesh et al., 2022). *Sphaerotheca maskeyi* a medium-sized frog (SVL=47mm) and differs from the congeners in having smooth skin without any warts or tubercles and a uniformly colored reddish-brown dorsum (Schleich, 1998).

Rhacophoridae

Commonly found across tropical regions, the members of this family are generally known as tree and bush frogs; the species are mostly arboreal and tend to have dilated toe disks, which aid in movement within their habitats.

A single species of *Polypedates maculatus* was encountered during the survey. The species is a medium to large-sized frog (SVL= 88mm), with chestnut to brownish yellow and sometimes grey dorsum.

7.3.2 Reptiles of Godavari Basin

A total of 5 species of reptiles were encountered during the survey belonging to 2 families of a single order (Squamata) within the state of Maharashtra in Godavari riverscape with a diversity index of H'=1.61. Amongst the two families that were encountered the dominant family was Colubridae (n=3) followed by Gekkonidae (n=2) (Figure 7.5).

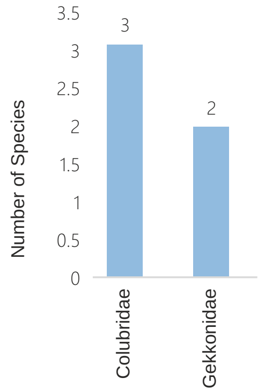


Figure 7.5 Number of Reptile species in various families of recorded in the Godavari River.

7.3.2.1 Richness and diversity of Reptiles across the various segments

The species richness across the segments within Maharashtra region in the Godavari River ranged from a minimum of 1 to a maximum of 2. Segments 6 had the maximum richness (2 species), and Segments 8, 9, 13 had the least richness (one species) (Figure 7.6).

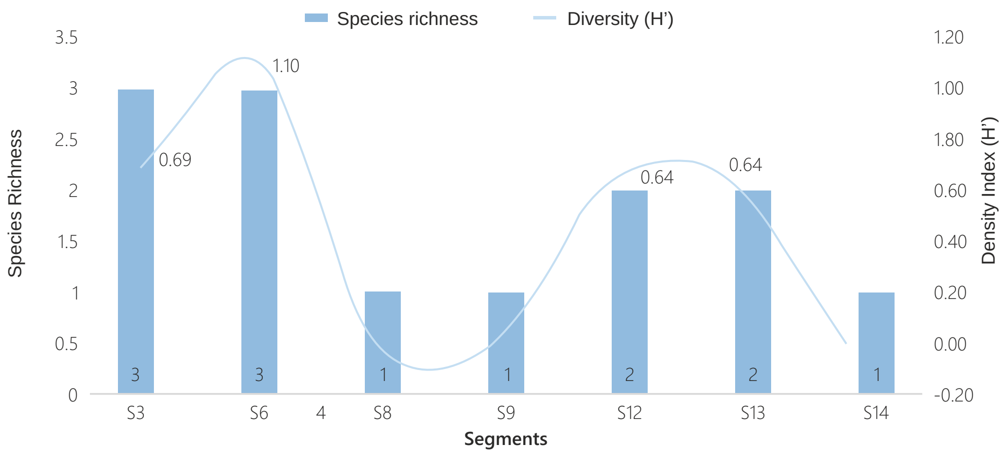


Figure 7.6 Richness and diversity of Reptiles recorded at various sampling segments in the Godavari River.

7.3.2.2 Distribution of Reptilian species

The analysis showed that none of the reptiles encountered were found to be widely distributed as the species encountered viz., *Hemidactylus flaviviridis, Hemidactylus triedrus, Fowlea piscator, Lycodon aulicus*, and *Ptyas mucosa* were found in only one location along Godavari River (Table 7.2).

The characteristics and richness status of each reptilian family are described below.

Gekkonidae

A globally distributed family with more diversity towards the tropics. They exist in a multitude of habitats ranging from arboreal to terrestrial and even near human habitation. Two species viz., *Hemidactylus flaviviridis* and *Hemidactylus triedrus* were encountered

Table 7.2
Distribution of reptiles in the Godavari River

Species	S 1	S 3	S 4	S 6	S 8	S 9	S 12	S 13	S 14
Hemidactylus flaviviridis	-	-	-	-	-	+	-	-	-
Hemidactylus triedrus	-	-	-	-	-	-	-	+	-
Fowlea piscator	-	-	-	-	+	-	-	-	-
Lycodon aulicus	-	-	-	+	-	-	-	-	-
Ptyas mucosa	-	-	-	+	-	-	-	-	-

during the survey. This genus is particularly known to prefer human habitation and is found quite abundantly. *Hemidactylus flaviviridis*, a medium to large-bodied lizard (180mm), is also known as yellow bellied or northern house gecko is found widely distributed in the northern and central parts of India while being completely absent towards the Southern side. The species can be distinguished from its congeners in having a more swollen tail base than any other species and a distinct yellow-colored ventral side (Daniels et al., 2005). *Hemidactylus triedrus* is a medium-sized gecko (45-74 mm) that can be identified with the presence of a light brown dorsum having a thin paired black-edged white band at regular intervals (Mirza et al., 2018).

Colubridae

This particular group of snakes can be encountered on every continent worldwide except Antarctica. This family stands out as the largest family of snake, containing the highest number of species. Three species viz., *Fowlea piscator, Lycodon aulicus*, and *Ptyas mucosa* belonging to three genera were encountered during the survey. *Fowlea piscator* is a commonly found colubrid across India. The species is usually found near water bodies such as lakes, ponds, marshes, and agricultural fields. The species can be identified by a green to dark brown body with checkered patterns all across, but the coloration and patterns tend to differ based on geographical distribution. *Lycodon aulicus* is a medium-sized snake that is both widely distributed and commonly found near human habitation, and it can be easily identified with the presence of a creamy white colored collar behind the head with a blackish brown or dark brown dorsum having creamy white cross bars (Ganesh and Vogel, 2018).

Ptyas mucosa is one of the largest colubrid snakes found in India. The species can be identified by the presence of a sleek body with a head smaller than the neck. Body coloration varies from black to whitish brown. Further, the presence of slight black banding, which might be absent in some individuals, and distinct black color net-like pattern. The tail are other distinguishing characters.

7.4 Discussion

The present survey recorded 12 species of amphibians in the Godavari River basin. It is higher than the total amphibians recorded earlier in the Godavari River basin (NRCD-WII, 2022). It accounts for 75% of Telangana (Srinivasulu and Kumar, 2022), 63% of the Bastar Mandla, Seon (Chandra and Gajbe, 2005), 60% of Nallamala Hills, Eastern Ghats, India (Srinivasulu and Das, 2008), and 75% Araku valley (Chettri and Acharya, 2020). It is higher than the total amphibians recorded from various locations in the Godavari River (Deuti et al., 2014), the East Godavari, West Godavari (Naik et al., 2012), and Bastar district Chhattisgarh, India (Gangopadhyay et al., 2015). Few studies attempted to assess amphibians in the Godavari basin, and majority of them studies describe new species from this basin, including two species reported from the East Godavari district (Srinivasulu and Das, 2008) and regional record for *Firouzophrynus hololius*, which is a relatively uncommon bufonid found in the Godavari basin. The amphibian's distribution revealed that majority of the species is restricted to the eastern side of the basin. As the survey was only conducted in Maharashtra, this uncommon toad was not encountered anywhere else. An individual of *Minervarya cf. syhadrensis* was found during the study, the confirmation of which is pending, could be the first record of the species within the basin. Therefore, detailed surveys of riverine zones and conservation efforts are necessary for habitat assessments, and conservation of amphibian fauna is inevitable.

The assessment of reptiles recorded a total of 5 species of reptiles, it accounts for around 36% of the reptiles recorded from the Godavari basin (NRCD-WII, 2022). It is about 28% of the reptiles in the East Godavari West Godavari (Naik et al., 2012). It accounted for about 22% of the reptiles reported from the Bastar district of Chhattisgarh (Gangopadhyay et al., 2015) and Chandrapur dist., East Godavari, West Godavari (Khate and Bawaskar, 2020). It is about 8% of the reptiles in the Nallamala Hills, Eastern Ghats, India (Srinivasulu and Das, 2008). It accounts for the 6% of the reptilian fauna recorded in the Bastar, Mandla, and Seoni in the Godavari basin (Chandra and Gajbe, 2005). There is no comprehensive study on the reptiles in the Godavari basin. The majority of studies were on new records of reptile species and range extensions. Based on the literature, the Godavari basin had the largest freshwater turtle species found in India. Critically endangered *Pelochelys cantorii* is a rare freshwater turtle found in the brackish water along the eastern coasts of Godavari (Sirsi, 2010). According to Rao, (1998) Visakhapatnam has a breeding population of *Lepidochelys olivacea*. Therefore, a comprehensive assessment of herpetofauna and anthropogenic threats has to be conducted to conserve these threatened species and habitats in the Godavari basin. Table 7.3 summarizes species of herpetofauna recorded from various parts of the Godavari River basin in India.

Table 7.3: Status of Herpetofauna in the Godavari Riverscape, India

Study Area	Snake	Lizard	Turtle	Overall Amphibians	Overall Reptiles	Reference
Overall, Godavari Basin	-	-		5	14	NRCD-WII, (2022)
Araku valley	6	10		16		Chettri and Bhupathy, (2010)
Bastar district Chhattisgarh, India.				10	23	Gangopadhyay et al., (2015)
Bastar, Mandla, Seoni				19	85	Chandra and Gajbe, (2005)
Chandrapur district, East Godavari, West Godavari.					2	Sirsi, (2010)
East Godavari, West Godavari				4	18	Naik et al., (2012)
Nallamala Hills, Eastern Ghats, India				20	64	Srinivasulu and Das, (2008)
Telangana state, India	40	35	6	16		Srinivasulu and Kumar, (2002)
Various localities				7		Deuti et al., (2014)
Visakhapatnam, East Godavari, Pune					3	Rhodin et al., (2017)

References

Chandra K and Gajbe PU (2005) An inventory of herpetofauna of Madhya Pradesh and Chhattisgarh. Zoos Print Journal, 20(3), pp.1812-1819.

Chettri B and Acharya BK (2020) Distribution of amphibians along an elevation gradient in the Eastern Himalaya, India. Basic and Applied Ecology, 47, 57-70.

Chettri, B and Bhupathy, S (2010) Three little known reptile species from the Araku Valley, Eastern Ghats with notes on their distribution. Journal of Threatened Taxa 2(8): 1109-1113.

Crump ML and Scott Jr NJ (1994) Visual encounter surveys. Pages 84–92 in Heyer WR, Donnelly MA, McDiarmid RW, Hayek LC, Foster MS, editors. Measuring and monitoring biological diversity, standard methods for amphibians. Smithsonian Institution Press, Washington D.C., USA.

Daniels SR, Heideman NJL, Hendricks MGJ, Mokone ME and Crandall KA (2005) Unraveling evolutionary lineages in the limbless fossorial skink genus Acontias (Sauria: Scincidae): are subspecies equivalent systematic units? Molecular Phylogenetics and Evolution, 34, 645–654.

Deuti K, Sethy, PGS and Ray S (2014) Amphibians of the Eastern Ghats. Records of the Zoological survey of India, pp.119-144.

Dinesh KP, ChannakesharamU, Deepak P Shabnas A, Ghosh A and Deuti K (2022) Discovery of a new species of Euphlyctis (Anura: Dicroglossidae) from the western costal plains of peninsular India. Zootana 5100: 419-434

Dubois A, Ohler A and Biju SD (2001) A new genus and species of Ranidae (Amphibia, Anura) from south-western India. Alytes 19(2–4): 53–79.

Frauendorf TC, Colón Gaud C, Whiles MR, Barnum TR, Lips KR, Pringle CM and Kilham SS (2013) Energy flow and the trophic basis of macroinvertebrate and amphibian production in a neotropical stream food web. Freshwater Biology, 58(7), 1340-1352.

Ganesh SR and Vogel G (2018) Taxonomic reassessment of the common Indian wolf snakes Lycodon aulicus (Linnaeus, 1758) complex (Squamata: Serpentes: Colubridae). Bonn Zoological Bulletin, 67(1), 25-36.

Garg S, Suyesh R, Das A, Jiang J, Wijayathilaka N, Amarasinghe AT and Biju SD (2018) Systematic revision of Microhyla (Microhylidae) frogs of South Asia: a molecular, morphological, and acoustic assessment. Vertebrate Zoology, 69, 1-71.

Gangopadhyay A, Dutta AL and Manna PK (2015) A preliminary survey of Herpetofauna of Bastar district (Chhattisgarh), India.J.Exp.Zool.India 18(1): 409-416.

Hopkins GR and Brodie JrED (2015) Occurrence of amphibians in saline habitats: a review and evolutionary perspective. Herpetological Monographs, 29(1), 1-27.

Khate DD and Bawaskar K (2020) Base-line data on herpetofaunal diversity in the Chandrapur District of Maharashtra, India. Reptiles & Amphibians, 26(3), pp.180-188.

Khatiwada JR, Zhao T and Jianping J (2020) Variation of body temperature of active amphibians along elevation gradients in eastern Nepal Himalaya. Journal of Thermal Biology. 92. 102653. 10.1016/j.jtherbio.2020.102653.

Loubser GJJ, Mouton PLF and Nel JAJ (2001) The ecotourism potential of herpetofauna in the Namaqua National Park, South Africa. South African Journal of Wildlife Research, 31(1), 13-23.

Mirza ZA, Gowande, GG, Patil R, Ambekar M and Patel H (2018) First appearance deceives many: disentangling the Hemidactylus triedrus species complex using an integrated approach. PeerJ, 6, e5341.

Naik DR, Rahiman SA and Hossain K (2012) Vulnerable endangered, threatened and rare species categories in the submergence area of Polavaram area. European Journal of Experimental Biology, 2(1), pp.288-296.

NRCD-WII (2022) Godavari Riverscape: Ecological status and trends, Ganga Aqualife Conservation Monitoring Centre, Wildlife Institute of India, Dehra dun. Uttarakhand, India. 139 pp.

Rao MS (1998) Present Status of the Olive Ridley Sea Turtle, Lepidochelys olivacea (eschscholtz) Along the Andhra Pradesh Coastline, India. In Annual Sea Turtle Symposium (p. 287).

Rhodin AGJ, Stanford CB, Dijk PPV, Eisemberg C, Luiselli L, Mittermeier RA, Hudson R, Horne BD, Goode EV, Kuchling G, Walde A, Baard EHW, Berry KH, Bertolero A, Blanck TEG, Bour R, Buhlmann KA, Cayot LJ, Collett S and Vogt RC (2018) Global Conservation Status of Turtles and Tortoises (Order Testudines), Chelonian Conservation and Biology, 17(2):135–161.

Riyanto A, Sulaeman TN, Rachman N, Chaidir DM, Trilaksono W and Farajallah A (2019) Herpetofauna diversity, potential ecotourism in Mount Galunggung, West Java, Indonesia. Biodiversitas Journal of Biological Diversity, 20(4), 1173-1179.

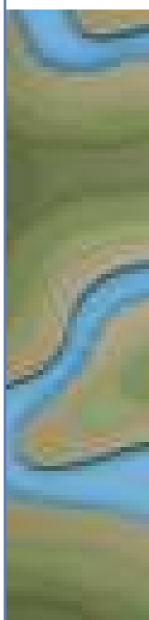
Schleich HH and Anders CC (1998) Tomopterna maskeyi spec. nov. from Nepal (Amphibia, Anura). Contributions to the Herpetology of South Asia, pp. 57-72. Fuhlrott-Museum, Germany.

Sirsi S (2010) A progress report on reconnaissance of softshell turtles in the states of Karnataka and Andhra Pradesh. Turtle Survival Alliance and Madras Crocodile Bank Trust.

Srinivasulu C and Das I (2008) The herpetofauna of Nallamala Hills, Eastern Ghats, India: an annotated checklist, with remarks on nomenclature, taxonomy, habitat use, adaptive types and biogeography. Asiatic Herpetological Research, 11, 110-131.

Srinivasulu C and Kumar GC (2022) A checklist of herpetofauna of Telangana state, India. Journal of Threatened Taxa, 14(6), 21266-21281.

Valencia-Aguilar A Cortés-Gómez AM and Ruiz-Agudelo CA (2013) Ecosystem services provided by amphibians and reptiles in Neotropical ecosystems. International Journal of Biodiversity Science, Ecosystem Services & Management, 9(3), 257-272.



08

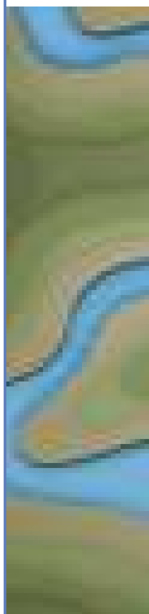
AVIFAUNA

08

AVIFAUNA

Abstract

We evaluated the status, distribution and stretches of conservation priority in the Godavari River from July to October 2022 and from December 2022 to March 2023. A total of 210 species belonging to 21 orders, 66 families and 157 genera were recorded in the Godavari River with a diversity of 4.16. Of the total species recorded 55.24 % (n=116) were terrestrial, 36.19% (n=76) were waterbirds and 8.57% (n=18) were water dependent/associate species. Northern Pintail (Anas acuta), River Tern (Sterna aurantia) and Northern Shoveler (Spatula clypeata) were the most abundant species among the waterbirds and Red-vented Bulbul (Pycnonotus cafer), Green Bee-eater (Merops orientalis) and Ashy Prinia (Prinia socialis), were the frequently sighted species among the terrestrial birds. Among the recorded species, three were endangered, two were vulnerable and eight were near threatened species. Moreover, 23 bird species belong to the schedule I of Wild Life (Protection) Amendment Act, 2022. A total of 954 km stretch, including 572 km in the upper zone, 234 km in the middle and 148 km in the lower zone of the Godavari River was found suitable for waterbirds and water dependent/associated species. Birds in Godavari River are threatened with habitat degradation and destruction due to sprouting human population, rapid urbanization, industrialization, mining, water abstraction and increasing piligrimage and tourism activity. Information on the status and distribution of birds facilitates their conservation owing to increasing anthropogenic pressures. This stretch should be brought under the purview of Wild Life (Protection) Amendment Act, 2022 for conservation of birds in Godavari River.



8.1 Introduction

Freshwater biodiversity and inland waters are important natural resources from an educational, scientific, cultural, artistic and economic viewpoint and interests of all the people, nations and governments depend on their conservation and management (Dudgeon et al., 2006). The demand for water from the domestic, industrial and agricultural sectors is causing stress to India's freshwater ecosystems, particularly the rivers (NRCD-WII, 2022). Globally, freshwater ecosystems are facing direct threat from human induced climate change and anthropogenic activities (Meybeck, 2003; Vörösmarty, 2005; UNESCO, 2009) and may be considered the most threatened ecosystem worldwide (Dudgeon et al., 2006). Large scale changes in land use pattern, urbanization, industrialization and engineering projects that optimize human access to water, including reservoir construction, irrigation and linking rivers basins (interbrain transfers) effect water systems (Meybeck, 2003; Vörösmarty, 2005; Karl et al., 2009; Vörösmarty, 2010).

Birds are the vital component of freshwater ecosystems (Ormerod and Tyler, 1993) and are of global importance for their high recreational and economic values (Das et al., 2014). Because of their roles in pollination, seed dispersal, and pest control, birds provide supporting services to ecosystems all over the world (Whelan et al., 2008). About 23% of waterbirds population worldwide is declining as a result of habitat loss, pollution, overhunting, biological invasions and climate change implications (Wang et al., 2018).

Godavari basin supports 384 species of birds including threatened aquatic birds such as critically endangered Spoon-billed Sandpiper (*Eurynorhynchus pygmeus*), endangered species, Great Knot (*Calidris tenuirostris*), Indian Skimmer (*Rynchops albicollis*), Black-bellied Tern (*Sterna acuticauda*), vulnerable, Common Pochard (*Aythya ferina*), River Tern (Sterna aurantia) near threatened species Marbled Duck (*Marmaronetta angustirostris*), Black-headed Ibis (*Threskiornis melanocephalus*), Spot-billed Pelican (*Pelecanus philippensis*), Woolly-necked Stork (*Ciconia episcopus*), Lesser Flamingo (*Phoeniconaias minor*) and Oriental Darter (*Anhinga melanogaster*) (NRCD-WII, 2022). These birds are however threatened by sprouting human population along the course of River Godavari (from 1,63,48,837 in 1951 to 5,12,47,255 in 2011) with urbanization and industrialization have severally deteriorated the water availability and quality of Godavari River. Besides the over-exploitation of river resources, illegal sand mining is adversely impacting the ecology of the Godavari River thereby impacting the habitat for ground nesting birds. The forest cover witnessed a decrease of 0.25% and 3.93%, with a corresponding increase in the urban and built-up areas (Hengade and Eldho, 2019). Additionally, as per the Central Water Commission, abstraction of water, construction of large number of dams such as karanjwan dam, Jayakwadi dam and Sriram Sagar dam have impacted the ecological flow of Godavari River. All these factors cumulatively impact the status and distribution of birds.

In spite if this, studies to assess the status and distribution of birds in Godavari River are lacking except few short term fragmented studies. Most studies on avifauna have been carried out in the protected area of the Godavari Basin (Balkhande et al., 2014; Balkhande et al., 2017; Chavan et al., 2012 and Pawar et al., 2019). To bridge the gap in knowledge, we conducted a rapid assessment of the Godavari River to determine the status and distribution along with areas of hotspot of bird diversity for their effective conservation.

8.2 Methods of Assessment

Status of birds in the Godavari River was assessed employing MacKinnon's species richness method (MacKinnon and Phillips, 1993). During the survey, lists of 20 species were generated by walking one km transect during morning hours (0700- 1000 hours) and evening (0530 - 0630 hours). Once a list of 20 species was completed, another list was initiated. Bird species were recorded in the sampling transact using both visually and auditory stimuli (rare cases) along with their numbers. Unidentified species were photographed for identification or recorded at the genus level. Identification of species was based on Grimmet et al. (2019). During the surveys, when waterbirds and water associated/dependent birds were sighted, a total count of all the individuals present at that location was followed. The information on migratory status of birds were obtain from the State of Indian Birds (SoIB 2023).

Birds were categorised as terrestrial, waterbirds and water associated/dependent following the checklist of Indian Waterbirds (Kumar et al., 2003). Bird species were segregated into different guilds such as insectivore, carnivore, omnivore, granivore, herbivore, nectarivore, and frugivore, considering their most frequent mode of foraging (del-Hoyo et al., 2018) and their relative proportion were calculated. All individual sightings of terrestrial birds from each transect were pooled, and bird species were ranked as Rare (1-5), Common (6-25), Abundant (26-50) and very abundant (>51) following Ahmad et al. (2019).

The abundance of waterbirds including water associated/dependent birds was assessed through calculating their relative abundance.

$$\text{Relative abudance} = \frac{\text{Abudance of } i^{th} \text{ species}}{\text{Total abudance of all species}} \times 100$$

Figure 8.1 Recording of avifauna in the Godavari River

8.3 Status of avifauna in the Godavari River

A total of 210 species belonging to 21 orders, 66 families and 157 genera were recorded in the Godavari River with a diversity of 4.16 (Table 8.1). Out of the total species recorded in the Godavari River, 55.24% (n=116) were terrestrial, 36.19% (n=76) were waterbirds and 8.57% (n=18) were water dependent/associate species (Figure 8.2). An analysis of data revealed that majority of the bird species were resident species (59.05%), followed by winter visitors (30.48%) and local migrants (10.48%) (Figure 8.3).

Avifauna of Conservation Significance

Among the recorded bird species, three species viz., Great Knot (*Calidris tenuirostris*), Indian Skimmer (*Rynchops albicollis*) and Black-bellied Tern (*Sterna acuticauda*) listed as Endangered (EN), two species listed as Vulnerable (VU) viz., Common Pochard (*Aythya farina*) and River Tern (*Sterna aurantia*) and eight species viz., Eurasian Oystercatcher (*Haematopus ostralegus*), River Lapwing (*Vanellus duvaucelii*), Black-tailed Godwit (*Limosa limosa*), Woolly-necked Stork (*Ciconia episcopus*), Oriental Darter (*Anhinga melanogaster*), Black-headed Ibis (*Threskiornis melanocephalus*), Grey-headed Fish-Eagle (*Icthyophaga ichthyaetus*) and Alexandrine Parakeet (*Psittacula eupatria*) listed as Near Threatened (NT) in the IUCN Redlist are having conservation significance (Table 8.2). Moreover, twenty three species are listed under the Schedule-I and 185 in Schedule-II of the Wild Life (Protection) Amendment Act, 2022 were recorded in the Godavari river (Appendix 8.1 and Plate 8.2).

Table 8.1 Summary of avifauna recorded in the Godavari River

Parameters	Avifauna	Upper zone	Middle zone	Lower zone	Overall
Orders		20	17	18	21
Families		61	45	54	66
Genera		128	94	106	157
	Overall	170	117	131	210
Species Richness	Terrestrial	95	68	74	116
	WB and WD/A	75	49	57	94
	Overall	3.74	3.12	3.54	4.16
Shannon-Wiener Diversity Index	Terrestrial	3.98	3.66	3.71	4.06
	WB and WD/A	2.78	2.34	3.01	3.47
	Overall	1	1	2	3
Endangered	Terrestrial	0	0	0	0
	WB and WD/A	1	1	2	3
	Overall	2	1	1	2
Vulnerable	Terrestrial	0	0	0	0
	WB and WD/A	2	1	1	2
	Overall	5	5	1	8
Near-threatened	Terrestrial	1	1	1	1
	WB and WD/A	4	4	0	7
	Overall	15	9	6	23
Schedule-I	Terrestrial	5	5	1	8
	WB and WD/A	10	5	5	15

WB = waterbirds WD/A water associated/dependent birds

Figure 8.2: Various birds groups recorded during the survey in the Godavari River

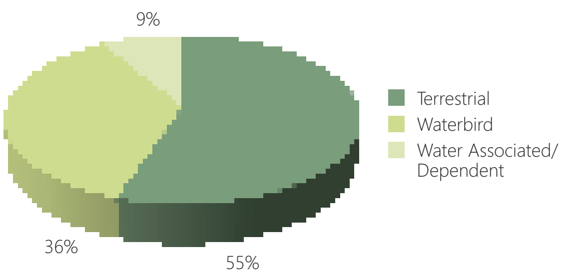
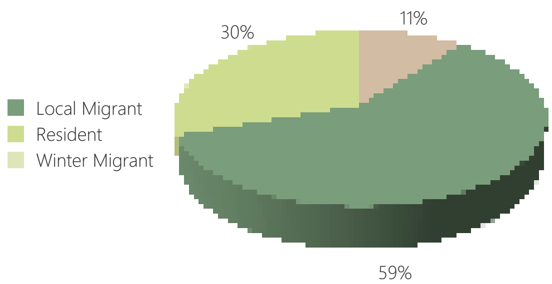


Figure 8.3: Migratory status of avifauna recorded in the Godavari River



Species	Water Association	IUCN status	WPA Status	Distribution
Great Knot	WB	EN	Sch-I	LZ
Indian Skimmer	WB	EN	Sch-I	LZ
Black-bellied Tern	WB	EN	Sch-I	UZ, LZ and MZ
Common Pochard	WB	VU	Sch-I	UZ
River Tern	WB	VU	Sch-I	UZ, LZ and MZ
Eurasian Oystercatcher	WB	NT	Sch-I	LZ
River Lapwing	WB	NT	Sch-I	LZ
Black-tailed Godwit	WB	NT	Sch-I	UZ
Woolly-necked Stork	WB	NT	Sch-I	UZ and MZ
Oriental Darter	WB	NT	Sch-I	UZ, LZ and MZ
Black-headed Ibis	WB	NT	Sch-I	UZ and MZ
Grey-headed Fish-Eagle	WDA	NT	Sch-I	MZ
Alexandrine Parakeet	TR	NT	Sch-I	UZ, LZ and MZ

Table 8.2 Threatened avifauna of the Godavari River

Species	Water Association	IUCN status	WPA Status	Distribution
Cotton Pygmy-Goose	WB	LC	Sch-I	UZ
Indian Peafowl	TR	LC	Sch-I	UZ and MZ
Demoiselle Crane	WB	LC	Sch-I	UZ
Common Greenshank	WB	LC	Sch-I	UZ
Gull-billed Tern	WB	LC	Sch-I	LZ
Cinnamon Bittern	WB	LC	Sch-I	UZ
Eurasian Spoonbill	WB	LC	Sch-I	UZ and MZ
Osprey	WDA	LC	Sch-I	LZ
Crested Serpent-Eagle	TR	LC	Sch-I	UZ
Short-toed Snake-Eagle	TR	LC	Sch-I	UZ and MZ
Changeable Hawk-Eagle	TR	LC	Sch-I	LZ
White-eyed Buzzard	TR	LC	Sch-I	MZ
Western Marsh Harrier	WDA	LC	Sch-I	UZ
Shikra	TR	LC	Sch-I	UZ, LZ and MZ
Brahminy Kite	WDA	LC	Sch-I	UZ and LZ
Indian Eagle-Owl	TR	LC	Sch-I	MZ
Small Minivet	TR	LC	Sch-I	UZ

WB- Waterbirds, WDA- Water Associated/Dependent birds, T-Terrestrial birds, EN- Endangered, VU-Vulnerable, NT-Near Threatened, LC- Least Concern, Sch-I- Schedule I, UZ- Upper Zone, MZ- Middle Zone, LZ- Lower Zone.

8.3.1 Water and water dependent/associated birds

A total of 94 water and water dependent/associated birds were recorded of a diversity of 3.47. Among the recorded species of water and water dependent/associated birds, Anatidae (n=14) was the dominant family and it was followed by Ardeidae (n=11), Scolopacidae (n=11) and Laridae (n=10) (Figure 8.5). 11 families of water and water dependent/associated birds in the Godavari River were represented by single species (Figure 8.5). Of the total water and water dependent/associated birds sighted, 46.81% were winter visitor, 10.64% were local migrant and 42.55% were resident species. Three species viz., Black-bellied Tern (*Sterna acuticauda*), Indian Skimmer (*Rynchops albicollis*) and Great Knot (*Calidris tenuirostris*) were endangered two species viz., Common Pochard (*Aythya farina*) and River Tern (*Sterna aurantia*) were vulnerable and seven species viz., Black-headed Ibis (*Threskiornis melanocephalus*), Black-tailed Godwit (*Limosa limosa*), Grey-headed Fish Eagle (*Icthyophaga ichthyaetus*), Oriental Darter (*Anhinga melanogaster*) and Woolly-necked Stork (*Ciconia episcopus*), Eurasian Oystercatcher (*Haematopus ostralegus*), River Lapwing (*Vanellus duvaucelii*) were near threatened.

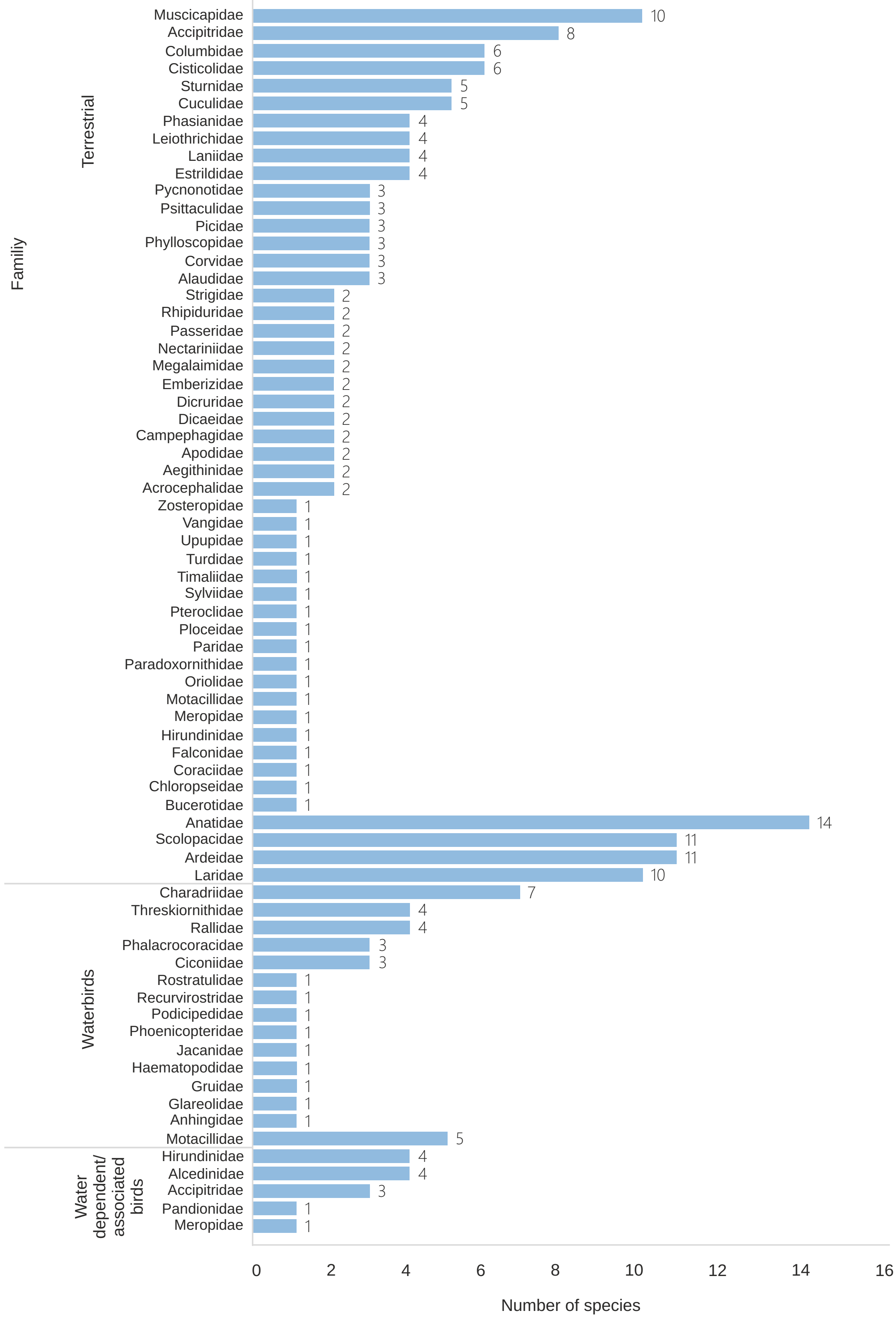
These species are also categorized as Schedule I and Schedule II of the Wild Life (Protection) Amendment Act, 2022 (Appendix 8.1).

8.3.2 Terrestrial Birds

A total of 116 terrestrial species were recorded in the Godavari River with a diversity of 4.06 in Godavari River. Among the terrestrial species, Muscicapidae (n=10), Accipitridae (n=8), and the Cisticolidae and Columbidae (n=6) respectively. 18 families of terrestrial birds in the rivers were represented by single species (Figure 8.5). Of the total terrestrial bird species, 72.41% of species were resident, 17.24% were winter visitor and 10.34% were local migrants (Figure 8.4). One species viz., Alexandrine Parakeet (*Psittacula eupatria*) was near threatened in IUCN Redlist of Threatened Species. Additionally, eight species viz., Crested Serpent-eagle (*Spilornis cheela*), Indian Eagle-Owl (*Bubo bengalensis*), Indian Peafowl (*Pavo cristatus*), Shikra (*Accipiter badius*), Short-toed Snake-Eagle (*Circaetus gallicus*), Small Minivet (*Pericrocotus cinnamomeus*), Changeable Hawk-Eagle (*Nisaetus cirrhatus*) and White-eyed Buzzard (*Butastur teesa*) were categorised as Schedule- I species in the Wild Life (Protection) Amendment Act, 2022 recorded during the survey.

Figure 8.4 Migratory status of water dependent/associated (left) and terrestrial birds (right) in the Godavari River

Figure 8.5 Number of species in various families of avifauna recorded along the Godavari River



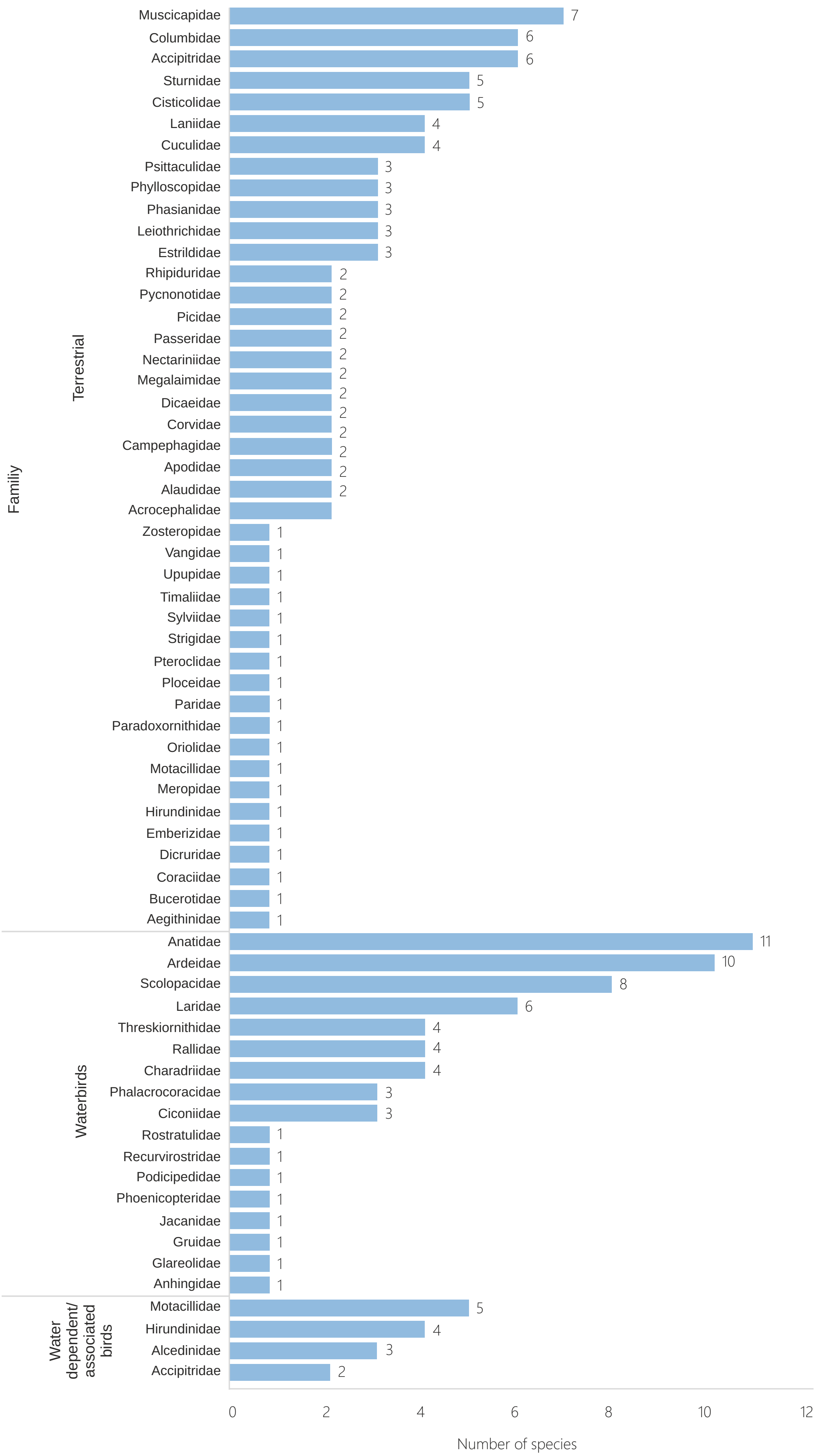
8.3.3 Avifauna in various zones of the Godavari River Basin

Upper zone of the Godavari River supports a total of 170 species of birds belonging to 128 genera and 64 families (Figure 8.6). Upper zone was comparatively richer than the middle and lower zone. Of the recorded species in the upper zone, 41.90% (75 species) of the birds were waterbirds and water dependent/ associated birds and remaining 53.07% were terrestrial. The diversity of the overall birds, terrestrial birds, waterbirds and water dependent/associated birds in the upper zone was 3.74, 3.98 and 2.78, respectively. The upper zone supports one endangered, two vulnerable and five near threatened water and water dependent/associated birds. Additionally, fifteen Schedule I species occur in the upper zone of the Godavari River of which ten were water and water dependent/ associated birds (Table 8.2).

A total of 117 species of birds belonging to 94 genera and 45 families were recorded with a diversity value of 3.12 in the middle zone. A total of 49 species (41.88%) of water and water dependent/associated birds were recorded from the middle zone of the Godavari River (Figure 8.7). The diversity of waterbirds and water associated/dependent birds is comparatively more diverse in middle zone than upper zone. The diversity of water and water dependent/associated birds and terrestrial birds in the middle zone was 2.34 and 3.66 respectively. Middle zone supports one endangered, one vulnerable and five near threatened species and nine Schedule I species of which four were water and water dependent/associated birds.

Lower zone of the Godavari supported 131 species belonging to 106 genera and 57 families with a diversity of 3.54 was recorded (Figure 8.8). Of the total bird species recorded in the middle zone, 56.49% (74 species) were terrestrial birds with diversity of 3.71, and remaining 43.51% of species (57 species) were water and dependent/associated birds , at a diversity of 3.01. Lower zone supports two endangered and one vulnerable species, were all three being water and water dependent/associated birds. This zone also supported one near threatened species and six Schedule I species, of which five were water and water dependent/associated birds.

Figure 8.6
Number of species in various families of birds in the upper zone of Godavari River



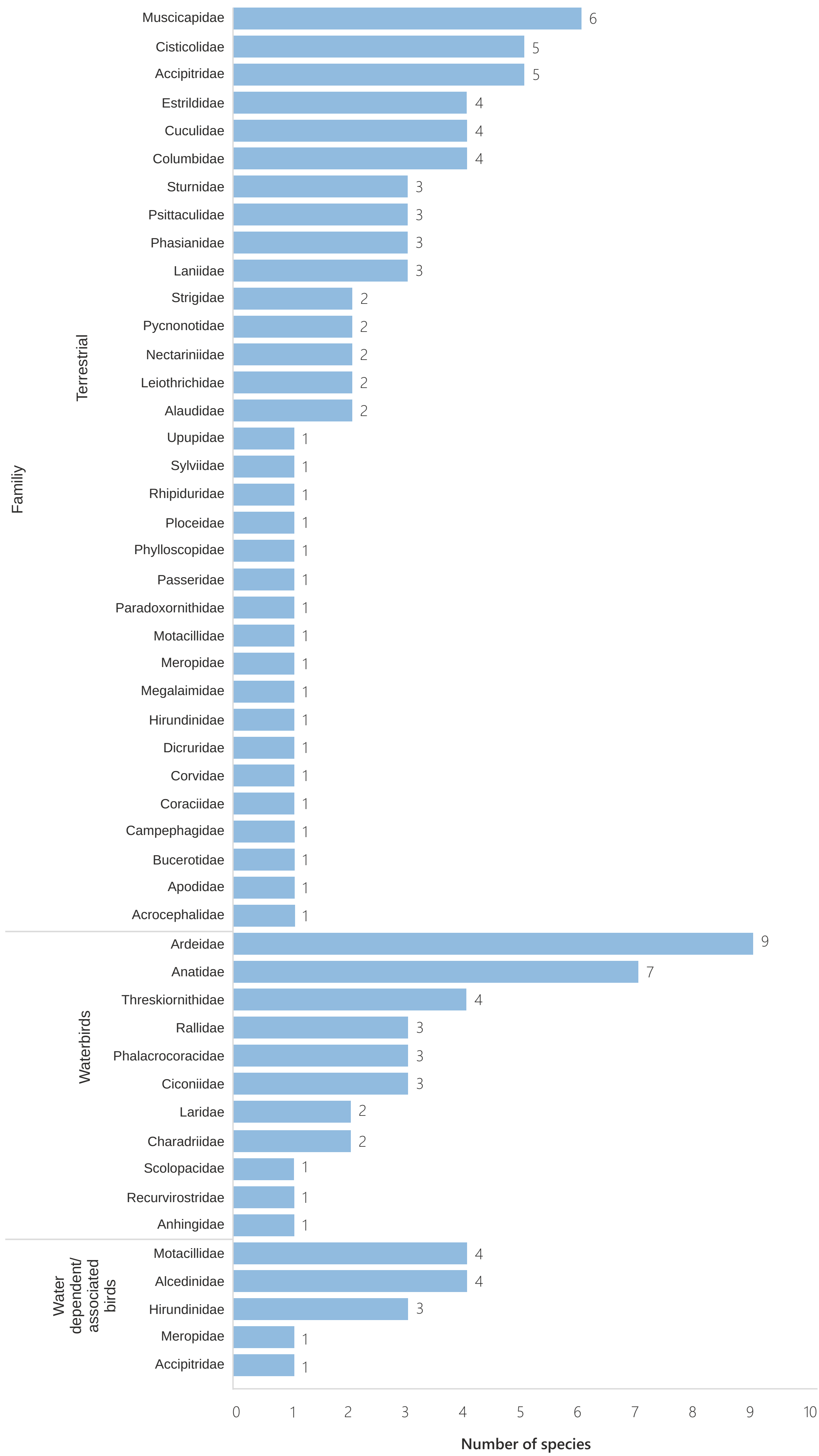
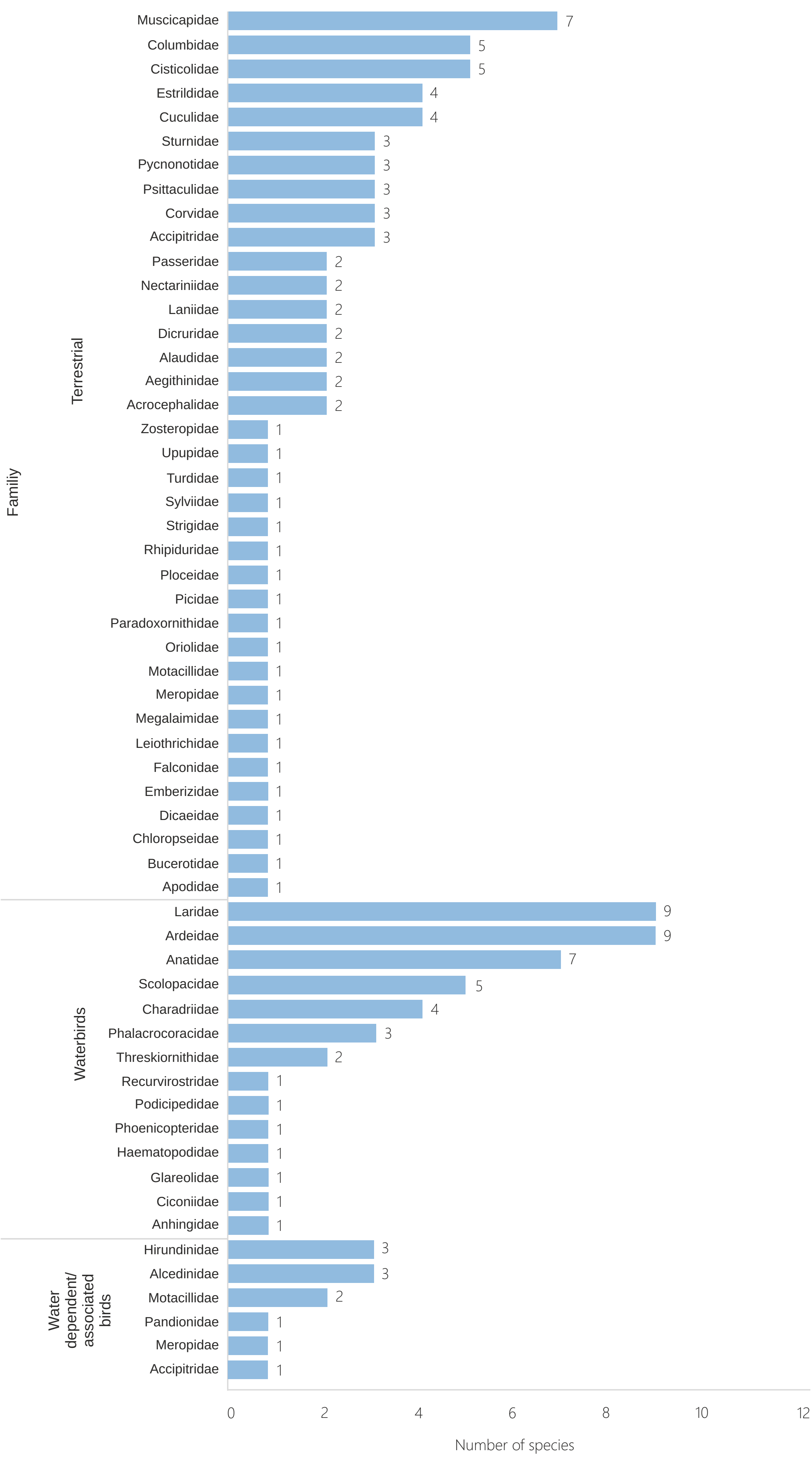


Figure 8.7 Number of species recorded in various families of birds in the middle zone of Godavari River

Figure 8.8 Number of species recorded in various families of bird recorded in the lower zone of Godavari River



8.3.4 Richness and diversity of avifauna in various sampling segments

An analysis on the richness and diversity in various sampling segments along Godavari River indicated an overall richness of birds ranging between 33 and 103 species and an overall diversity ranged between 2.12 and 4.23. The maximum richness of birds was observed at sampling segment 5 (103 species) and it was followed by sampling segment 6 (99 species), sampling segment 8 (86 species) and sampling segment 2 (80 species). Minimum richness of birds was observed at sampling segment 1 of upper zone (33 species). Maximum diversity of birds was observed at segment 11 (H'= 4.23) along with segment and minimum in segment 25 (H' =2.12). Figure 8.9 highlights the richness and diversity of birds recorded at various sampling segments in Godavari River.

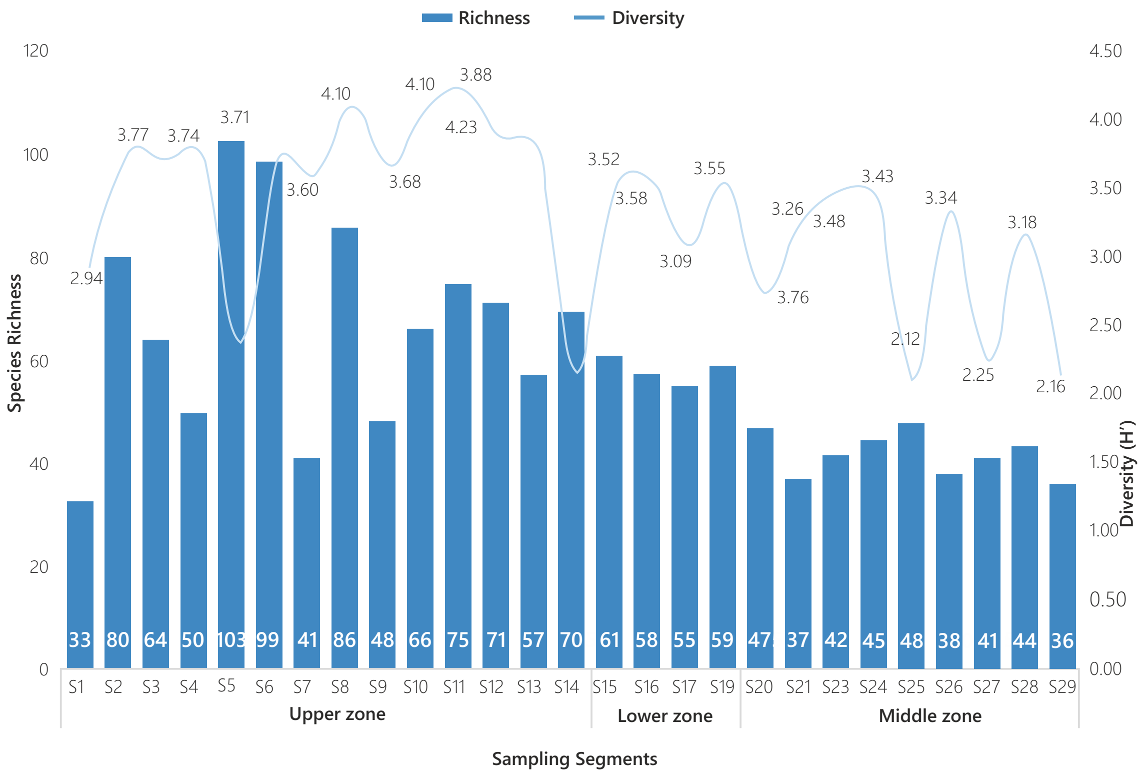


Figure 8.9 Richness and Diversity for overall avifauna recorded in the different sampling segments Godavari River

8.3.4.1 Waterbirds and water dependent/associated birds

Richness of water and water dependent/associated birds in the sampling segments ranged between 5 to 51 species and diversity between 0.93 and 3.46. Richness of water and water dependent/associated birds was maximum at sampling segment 5 (51 species) followed by segment 6 (41 species) and segment 2 (35 species). Richness of water and water dependent/associated birds was minimum at sampling segment 21 (5 species) and 4 (11 species). Diversity of water and water dependent/associated bird was maximum at segment 11 (H'=3.46) and minimum at sampling segment 21 (H'=0.93). Richness and diversity of water and water dependent/associated birds recorded at various sampling segments in Godavari River is highlighted in Figure 8.10.

8.3.4.2 Terrestrial birds

Richness of terrestrial birds in the Godavari River ranged between 18 to 58 species. Richness of terrestrial birds was maximum at sampling segment 6 (58 species) and minimum in sampling segment 29 (18 species). Diversity of terrestrial birds was maximum at sampling segment 6 (3.75) and minimum at segment 1 (2.681). Figure 8.11 highlights the richness and diversity of terrestrial birds recorded at various sampling segments in Godavari River.

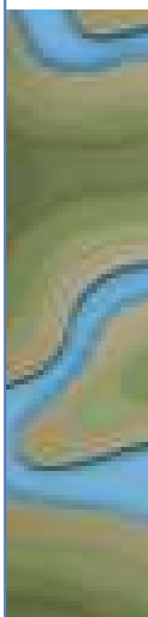


Figure 8.10
Richness and Diversity values for water dependent/associated birds of Godavari River

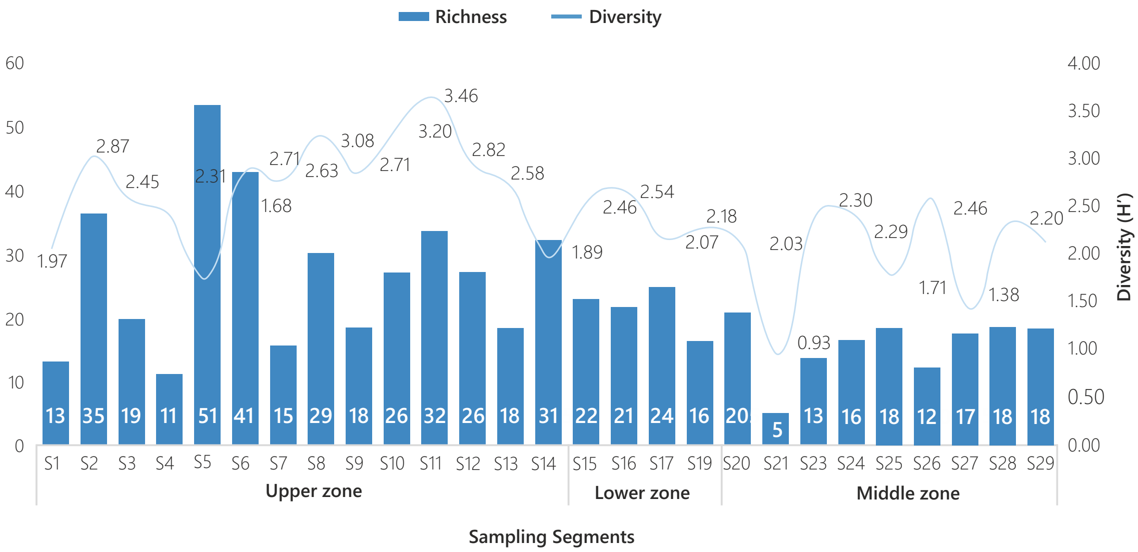
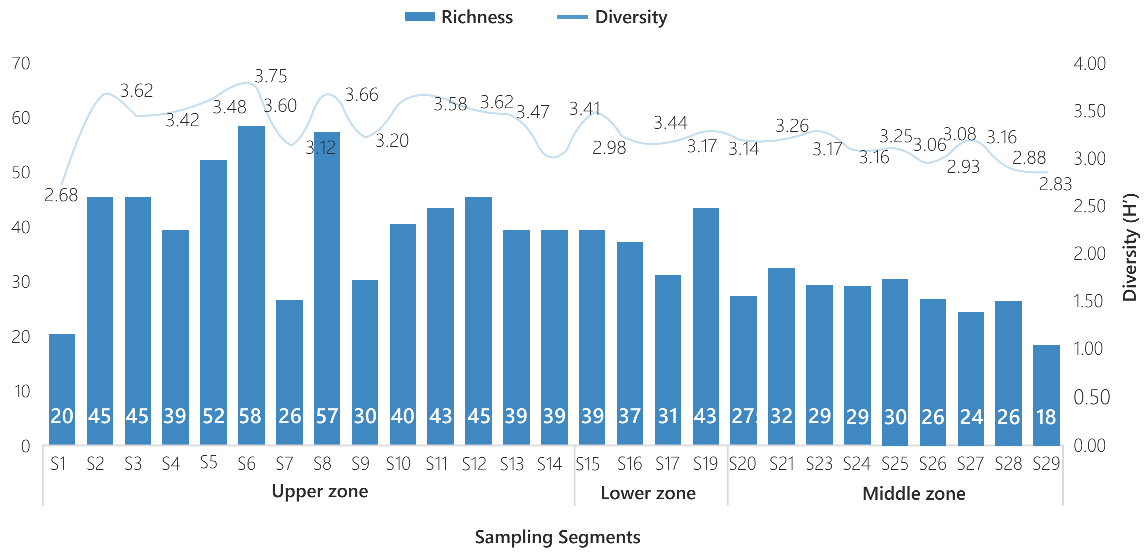


Figure 8.11
Richness and Diversity for terrestrial birds recorded in the Godavari River



8.3.7 Abundance of Avifauna

8.3.7.1 Waterbirds and water dependent/associated birds

Overall, Northern Pintail (*Anas acuta*) (12.9%) was the most abundant species in the Godavari River. It was followed by River Tern (*Sterna aurantia*) (11%), Northern Shoveler (*Spatula clypeata*) (7.7%), Brown-headed Gull (*Chroicocephalus brunnicephalus*) (6.2%), Great Cormorant (*Phalacrocorax carbo*) (4.6%) and Lesser Whistling-Duck (*Dendrocygna javanica*) (4%). Four species viz., Grey-headed Fish-Eagle (*Icthyophaga ichthyaetus*), Osprey (*Pandion haliaetus*), Pheasant-tailed Jacana (*Hydrophasianus chirurgus*) and Striated Heron (*Butorides striata*) were the least abundant species in the Godavari River with a relative abundance of 0.03% (Table 8.3).

In the upper zone also the relative abundance (19.5%) of Northern Pintail (*Anas acuta*) was more , followed by River Tern (*Sterna aurantia*) (17.2%) and Black-tailed Godwit (*Limosa limosa*) (15.3%). In the middle zone, Northern Shoveler (*Spatula clypeata*) recorded the maximum relative abundance (29%) followed by Lesser Whistling-Duck (*Dendrocygna javanica*) (13.7%) and Eastern Cattle Egret (*Bubulcus ibis*) (30.4). In the lower Zone, the relative abundance (13.8%) of Brown-headed Gull (*Chroicocephalus brunnicephalus*) was the maximum followed by Great Cormorant (*Phalacrocorax carbo*) (7.1%) and Little Cormorant (*Microcarbo niger*) (7.0%), respectively. Relative abundance of all waterbirds and water dependent/associated birds is highlighted in Table 8.3.

Table 8.3 Abundance of water and water dependent/associated birds recorded in the Godavari River

Species	Relation With River	Overall Relative Abundance	Upper Zone	Middle Zone	Lower Zone
Northern Pintail	WB	12.9	27.6	0.1	2.0
River Tern	WB	11.0	24.3	1.4	0.1
Northern Shoveler	WB	7.7	0.9	38.2	0.0
Brown-headed Gull	WB	6.2	0.2	0.0	16.3
Great Cormorant	WB	4.6	1.2	5.1	8.4
Lesser Whistling-Duck	WB	4.0	0.0	17.2	2.0
Little Cormorant	WB	3.3	0.3	0.5	8.3
Indian Cormorant	WB	3.3	0.3	0.5	8.2
Eastern Cattle Egret	WB	3.2	2.8	7.3	1.5
Black-tailed Godwit	WB	3.1	7.0	0.0	0.0
Tibetan Sand-Plover	WB	3.0	0.0	0.0	8.1
Caspian Tern	WB	3.0	0.0	0.0	8.1
Red-wattled Lapwing	WB	2.4	3.7	2.3	1.0
Bar-headed Goose	WB	2.0	2.8	3.3	0.5
Indian Skimmer	WB	1.8	0.0	0.0	5.0
Terek Sandpiper	WB	1.8	0.0	0.0	4.9
Small Pratincole	WB	1.7	1.9	0.0	2.3
Indian Pond-Heron	WB	1.4	1.6	3.0	0.4
Grey-headed Swamphen	WB	1.4	1.4	4.1	0.0
Citrine Wagtail	WD/A	1.3	0.1	0.0	3.3
Indian Spot-billed Duck	WB	1.2	0.4	0.7	2.5
Great Knot	WB	1.2	0.0	0.0	3.3
Gull-billed Tern	WB	1.2	0.0	0.0	3.3
Asian Openbill	WB	1.2	0.2	5.5	0.2
Intermediate Egret	WB	1.1	0.3	1.2	2.1
Grey Heron	WB	1.0	1.8	0.9	0.0
Black-winged Stilt	WB	0.9	1.4	0.1	0.7
Wire-tailed Swallow	WD/A	0.8	1.4	1.0	0.1
Eurasian Coot	WB	0.8	1.4	0.9	0.0
Glossy Ibis	WB	0.7	1.2	0.3	0.4
Barn Swallow	WD/A	0.7	1.0	0.5	0.4
Ruddy Turnstone	WB	0.6	0.0	0.0	1.6
Streak-throated Swallow	WD/A	0.6	0.6	0.2	0.9
Red-naped Ibis	WB	0.5	1.0	0.0	0.1
Ruddy Shelduck	WB	0.4	0.2	0.8	0.5
Red-rumped Swallow	WD/A	0.4	0.9	0.0	0.0

Species	Relation With River	Overall Relative Abundance	Upper Zone	Middle Zone	Lower Zone
White-throated Kingfisher	WD/A	0.4	0.5	0.6	0.2
Pied Kingfisher	WD/A	0.3	0.2	0.5	0.3
Black-bellied Tern	WB	0.3	0.3	0.6	0.2
White-browed Wagtail	WD/A	0.3	0.3	0.6	0.2
Eurasian Wigeon	WB	0.3	0.7	0.0	0.0
Black-headed Ibis	WB	0.3	0.5	0.3	0.0
Painted Stork	WB	0.3	0.6	0.1	0.0
Little Egret	WB	0.3	0.6	0.1	0.1
Purple Heron	WB	0.3	0.6	0.1	0.0
Little Grebe	WB	0.2	0.5	0.0	0.1
Little Ringed Plover	WB	0.2	0.5	0.1	0.0
Great Egret	WB	0.2	0.5	0.0	0.0
White-breasted Waterhen	WB	0.2	0.4	0.2	0.0
Woolly-necked Stork	WB	0.2	0.5	0.1	0.0
Common Teal	WB	0.2	0.5	0.0	0.0
Grey Wagtail	WD/A	0.2	0.4	0.0	0.0
Greater Flamingo	WB	0.2	0.2	0.0	0.2
Common Kingfisher	WD/A	0.2	0.2	0.6	0.0
Lesser Crested Tern	WB	0.2	0.0	0.0	0.5
Grey Plover	WB	0.2	0.0	0.0	0.5
Eastern Yellow Wagtail	WD/A	0.2	0.4	0.0	0.0
Wood Sandpiper	WB	0.1	0.3	0.0	0.0
Black-crowned Night Heron	WB	0.1	0.3	0.1	0.0
Red-crested Pochard	WB	0.1	0.3	0.0	0.0
Eurasian Oystercatcher	WB	0.1	0.0	0.0	0.3
Green Sandpiper	WB	0.1	0.3	0.0	0.0
Common Greenshank	WB	0.1	0.2	0.0	0.0
Blue-tailed Bee-eater	WD/A	0.1	0.0	0.1	0.3
Eurasian Spoonbill	WB	0.1	0.1	0.3	0.0
Temminck's Stint	WB	0.1	0.2	0.1	0.0
Brahminy Kite	WD/A	0.1	0.1	0.0	0.2
Common Pochard	WB	0.1	0.2	0.0	0.0
Demoiselle Crane	WB	0.1	0.2	0.0	0.0
Little Stint	WB	0.1	0.2	0.0	0.0
White Wagtail	WD/A	0.1	0.2	0.1	0.0

Species	Relation With River	Overall Relative Abundance	Upper Zone	Middle Zone	Lower Zone
River Lapwing	WB	0.1	0.0	0.0	0.2
Common Sandpiper	WB	0.1	0.2	0.0	0.0
Whiskered Tern	WB	0.1	0.0	0.0	0.2
Striated Heron	WB	0.1	0.2	0.0	0.0
Little Tern	WB	0.1	0.1	0.0	0.0
Common Redshank	WB	0.1	0.0	0.0	0.1
Pallas's Gull	WB	0.1	0.1	0.0	0.0
Oriental Darter	WB	0.1	0.0	0.2	0.0
Knob-billed Duck	WB	0.0	0.0	0.1	0.1
Yellow-wattled Lapwing	WB	0.0	0.1	0.0	0.0
Western Marsh Harrier	WD/A	0.0	0.1	0.0	0.0
Brown Crake	WB	0.0	0.1	0.0	0.0
Kentish Plover	WB	0.0	0.0	0.0	0.0
Common Shelduck	WB	0.0	0.0	0.0	0.0
Cotton Pygmy-Goose	WB	0.0	0.0	0.0	0.0
Common Merganser	WB	0.0	0.0	0.0	0.0
Cinnamon Bittern	WB	0.0	0.0	0.0	0.0
Western Reef-Egret	WB	0.0	0.0	0.0	0.0
Osprey	WD/A	0.0	0.0	0.0	0.0
Stork-billed Kingfisher	WD/A	0.0	0.0	0.1	0.0
Greater Painted-Snipe	WB	0.0	0.0	0.0	0.0
Pheasant-tailed Jacana	WB	0.0	0.0	0.0	0.0
Grey-headed Fish-Eagle	WD/A	0.0	0.0	0.0	0.0

WB=Waterbird, WD/A= water dependent/associated birds

8.3.7.2 Terrestrial birds

Analysis of frequency of sighting of terrestrial birds in the Godavari River revealed that 28% were rare, 31% that were common, 31% that were highly abundant and 10% that were abundant (Figure 8.12). Among the 116 terrestrial species, 36 were highly abundant. Red-vented Bulbul (*Pycnonotus cafer*), Green Bee-eater (*Merops orientalis*) Laughing Dove (*Spilopelia senegalensis*) and Ashy Prinia (*Prinia socialis*) were the most dominant among them. Among the total terrestrial bird species 11 were abundant, 36 were common and 33 were rare which are highlighted in the Table 8.3.

In the upper zone, there were 36% of species that were common, 24% of species were rare,19% were abundant and 21% were highly abundant viz., Red-vented Bulbul (*Pycnonotus cafer*), Ashy Prinia (*Prinia socialis*), Rosy Starling (*Pastor roseus*), Asian Green Bee-eater (*Merops orientalis*), Laughing Dove (*Spilopelia senegalensis*) and House Sparrow (*Passer domesticus*) (Figure 8.13). In the middle zone 50% of the species were rare, 34% were common, 13% of species were abundant and 3% were highly abundant. However, in the lower zone 49% of the species were rare, 30% were common, 17% of species were abundant and only 4% were highly abundant (Figure 8.12). Terrestrial bird species with their status in the Godavari River have been highlighted in Table 8.4.

Figure 8.12
Percentage of terrestrial bird species in different abundance categories in Upper, Middle and Lower zone of the Godavari River

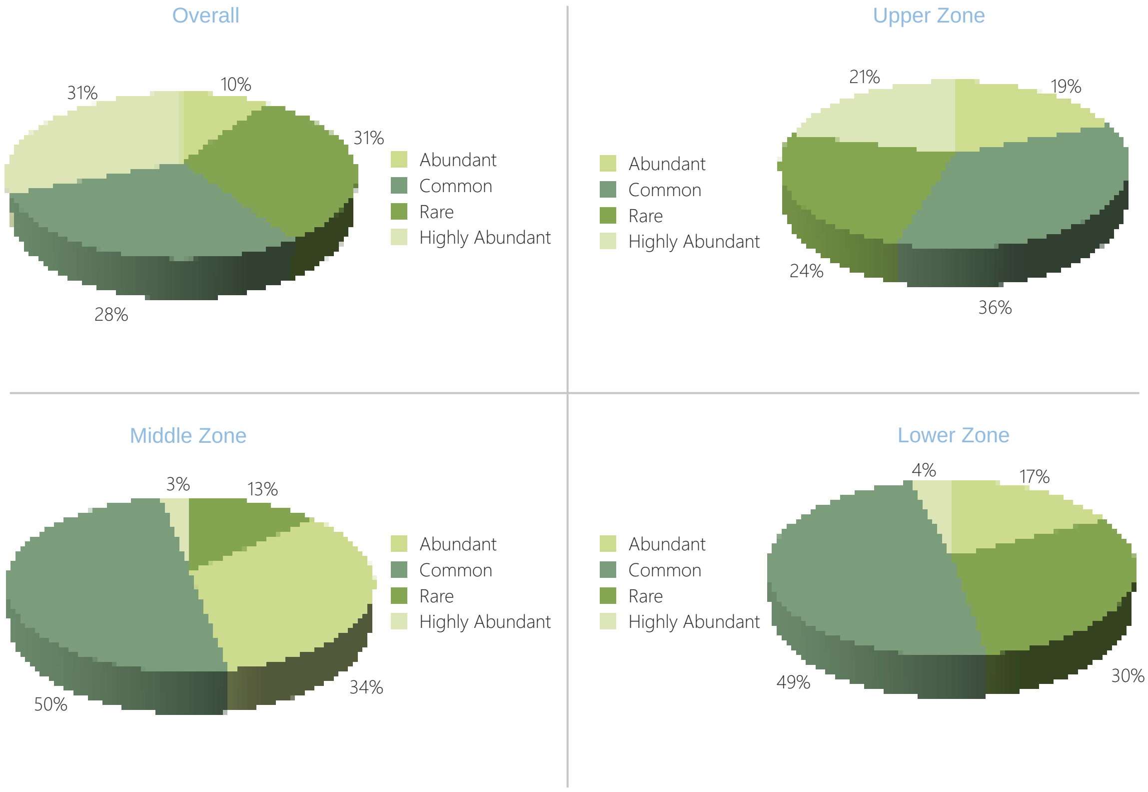


Table 8.4 Status of terrestrial birds in the Godavari River

Species	Upper Zone	Middle Zone	Lower Zone	Overall
Red-vented Bulbul	Highly Abundant	Common	Highly Abundant	Highly Abundant
Green Bee-eater	Highly Abundant	Highly Abundant	Abundant	Highly Abundant
Laughing Dove	Highly Abundant	Abundant	Abundant	Highly Abundant
Ashy Prinia	Highly Abundant	Abundant	Abundant	Highly Abundant
Rosy Starling	Highly Abundant	Common	Common	Highly Abundant
Common Myna	Highly Abundant	Common	Abundant	Highly Abundant
Asian Palm Swift	Highly Abundant	Common	Highly Abundant	Highly Abundant
Rose-ringed Parakeet	Highly Abundant	Abundant	Abundant	Highly Abundant
House Sparrow	Highly Abundant	Rare	Common	Highly Abundant
Purple Sunbird	Highly Abundant	Common	Abundant	Highly Abundant
House Crow	Highly Abundant	Common	Common	Highly Abundant
Rock Pigeon	Highly Abundant	Rare	Common	Highly Abundant
Pied Bushchat	Highly Abundant	Common	Common	Highly Abundant
Eurasian Collared-Dove	Highly Abundant	Common	Rare	Highly Abundant
Black Drongo	Highly Abundant	Rare	Common	Highly Abundant
Large-billed Crow	Highly Abundant	-	Common	Highly Abundant
Oriental Magpie-Robin	Highly Abundant	Common	Common	Highly Abundant
Dusky Crag-Martin	Highly Abundant	Rare	-	Highly Abundant
Brahminy Starling	Highly Abundant	-	-	Highly Abundant
Common Tailorbird	Highly Abundant	Rare	Rare	Highly Abundant
Baya Weaver	Abundant	Highly Abundant	Rare	Highly Abundant
Asian Pied Starling	Abundant	Abundant	Abundant	Highly Abundant
Red Munia	Abundant	Abundant	Common	Highly Abundant
Blyth's Reed Warbler	Abundant	Common	Abundant	Highly Abundant
Indian Robin	Abundant	Common	Common	Highly Abundant
Plum-headed Parakeet	Abundant	Common	Abundant	Highly Abundant
Asian Koel	Abundant	Common	Rare	Highly Abundant
Paddyfield Pipit	Abundant	Common	Common	Highly Abundant
Coppersmith Barbet	Abundant	Rare	Common	Highly Abundant
Rufous-tailed Lark	Abundant	Rare	Rare	Abundant
Yellow-eyed Babbler	Abundant	Common	Rare	Abundant
Jungle Babbler	Abundant	-	-	Abundant
Greater Coucal	Abundant	Rare	Common	Abundant
Indian White-eye	Abundant	-	Rare	Abundant
Long-tailed Shrike	Abundant	Common	Rare	Abundant
Cinereous Tit	Abundant	-	-	Abundant

Species	Upper Zone	Middle Zone	Lower Zone	Overall
Little Swift	Abundant	-	-	Abundant
Jungle Myna	Abundant	-	-	Abundant
Indian Silverbill	Common	Abundant	Highly Abundant	Highly Abundant
Purple-rumped Sunbird	Common	Common	Abundant	Highly Abundant
Plain Prinia	Common	Abundant	Common	Highly Abundant
White-browed Bulbul	Common	Common	Abundant	Highly Abundant
Tricoloured Munia	Common	Abundant	Rare	Highly Abundant
Lesser Whitethroat	Common	Common	Common	Abundant
Eurasian Hoopoe	Common	Common	Common	Abundant
Indian Peafowl	Common	Common	-	Common
Brown Rock Chat	Common	-	-	Common
Red Collared-Dove	Common	-	-	Common
Black Kite	Common	Rare	-	Common
Grey Francolin	Common	Rare	-	Common
Ashy-crowned Sparrow-Lark	Common	-	Common	Common
Tawny-bellied Babbler	Common	-	-	Common
Alexandrine Parakeet	Common	Rare	Rare	Common
Yellow-footed Green-Pigeon	Common	-	Rare	Common
Common Iora	Common	-	Common	Common
Common Babbler	Common	Rare	-	Common
Black-winged Kite	Common	Rare	-	Common
Shikra	Common	Rare	Rare	Common
Jungle Prinia	Common	Common	Rare	Common
Yellow-throated Sparrow	Common	-	Common	Common
Hume's Warbler	Common	-	-	Common
Indian Grey Hornbill	Common	Rare	Rare	Common
Indian Golden Oriole	Common	-	Common	Common
White-browed Fantail	Common	Rare	Rare	Common
Common Hawk-Cuckoo	Common	-	Rare	Common
Spotted Dove	Common	Rare	Rare	Common
Siberian Stonechat	Common	-	-	Common
Bay-backed Shrike	Common	Rare	-	Common
Brown-headed Barbet	Common	-	-	Common
Spot-breasted Fantail	Common	-	-	Common
Grey-breasted Prinia	Common	-	-	Common
Crested Serpent-Eagle	Common	-	-	Common
Clamorous Reed Warbler	Rare	-	Common	Common

Species	Upper Zone	Middle Zone	Lower Zone	Overall
Black Redstart	Rare	Rare	Rare	Common
Indian Roller	Rare	Rare	-	Common
Brown Shrike	Rare	Rare	Rare	Common
Spotted Owlet	Rare	Rare	Rare	Common
Pale-billed Flowerpecker	Rare	-	Rare	Common
Oriental Honey-buzzard	Rare	-	Rare	Common
Blue-faced Malkoha	Rare	Rare	Rare	Common
Thick-billed Flowerpecker	Rare	-	-	Rare
Common Woodshrike	Rare	-	-	Rare
Black-headed Cuckooshrike	Rare	Rare	-	Rare
Jungle Bush-Quail	Rare	-	-	Rare
Brown-capped Pygmy Woodpecker	Rare	-	-	Rare
Common Chiffchaff	Rare	-	-	Rare
Crested Bunting	Rare	-	-	Rare
Short-toed Snake-Eagle	Rare	Rare	-	Rare
Greenish Warbler	Rare	Rare	-	Rare
Chestnut-bellied Sandgrouse	Rare	-	-	Rare
Yellow-crowned Woodpecker	Rare	-	-	Rare
Small Minivet	Rare	-	-	Rare
Great Grey Shrike	Rare	-	-	Rare
Large Grey Babbler	Rare	-	-	Rare
Desert Wheatear	Rare	-	-	Rare
Scaly-breasted Munia	-	Abundant	Abundant	Highly Abundant
Yellow-billed Babbler	-	Common	Abundant	Highly Abundant
Red-whiskered Bulbul	-	-	Common	Common
Rufous Treepie	-	-	Rare	Rare
Golden-fronted Leafbird	-	-	Rare	Rare
Bluethroat	-	Rare	Rare	Rare
Black-headed Bunting	-	-	Rare	Rare
Zitting Cisticola	-	Rare	Rare	Rare
Rain Quail	-	Rare	-	Rare
Greater Flameback	-	-	Rare	Rare
Tickell's Blue Flycatcher	-	Rare	Rare	Rare
Indian Eagle-Owl	-	Rare	-	Rare
Singing Bushlark	-	Rare	-	Rare
Changeable Hawk-Eagle	-	-	Rare	Rare

Species	Upper Zone	Middle Zone	Lower Zone	Overall
Common Kestrel	-	-	Rare	Rare
Marshall's Iora	-	-	Rare	Rare
White-bellied Drongo	-	-	Rare	Rare
Orange-headed Thrush	-	-	Rare	Rare
Blue Rock-Thrush	-	-	Rare	Rare
Indian Cuckoo	-	Rare	-	Rare
White-eyed Buzzard	-	Rare	-	Rare

(Highly Abundant: >51 sightings, abundant: 26-50 sightings, Common: 6-25 sightings, rare: 1-5 sightings.)

8.3.8 Feeding guild

8.3.8.1 Waterbirds and water dependent/associated birds

Water and water dependent/associated birds in the Godavari River belong to four feeding guilds viz., carnivore, insectivore, omnivore and herbivore. Among these feeding guilds carnivorous with 42% of species was the dominant guild. Other feeding guilds of waterbirds and water dependent/associated birds viz., Insectivore, omnivore and herbivore were represented by 33%, 14% and 11%, respectively (Figure 8.14).

In the upper, middle and lower zone of the Godavari River, water and water dependent/associated birds were from four feeding guilds. Carnivore was the dominant guild in each of the upper, middle and lower zones represented by 41%, 43% and 48% respectively. Representation of various feeding guild in different zone of the river is highlighted in the Figure 8.13.

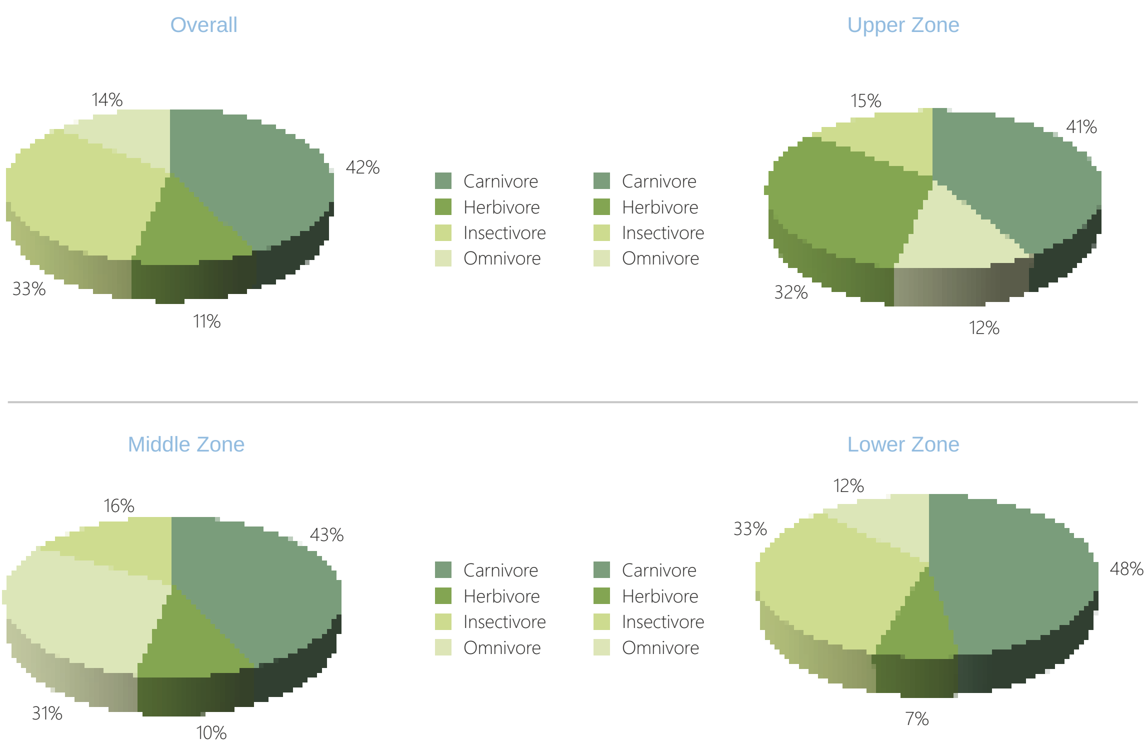
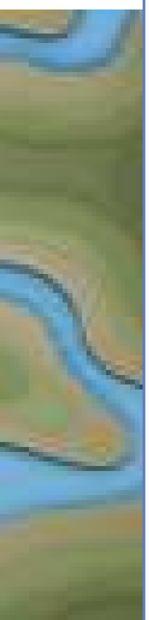


Figure 8.13 Proportion of foraging guilds of water birds and water dependent/ associated birds recorded in upper, middle and lower zones of the Godavari River



8.3.8.1 Terrestrial birds

Categorization of the terrestrial birds in to various feeding guilds revealed that they belong to six guilds. Insectivore guild was the dominant feeding guild with 48% of species. It was followed by granivore, omnivore, frugivore, carnivore and nectarivore representing 16%, 14%, 10%, 8% and 4% of species respectively.

Terrestrial birds in all three zones were of six feeding guilds (Figure 8.14) with insectivore birds being the dominant guilds, followed by omnivores in all zones. Figure 8.14 depicts different feeding guild of terrestrial avifauna in upper, middle and lower zones of the Godavari River.

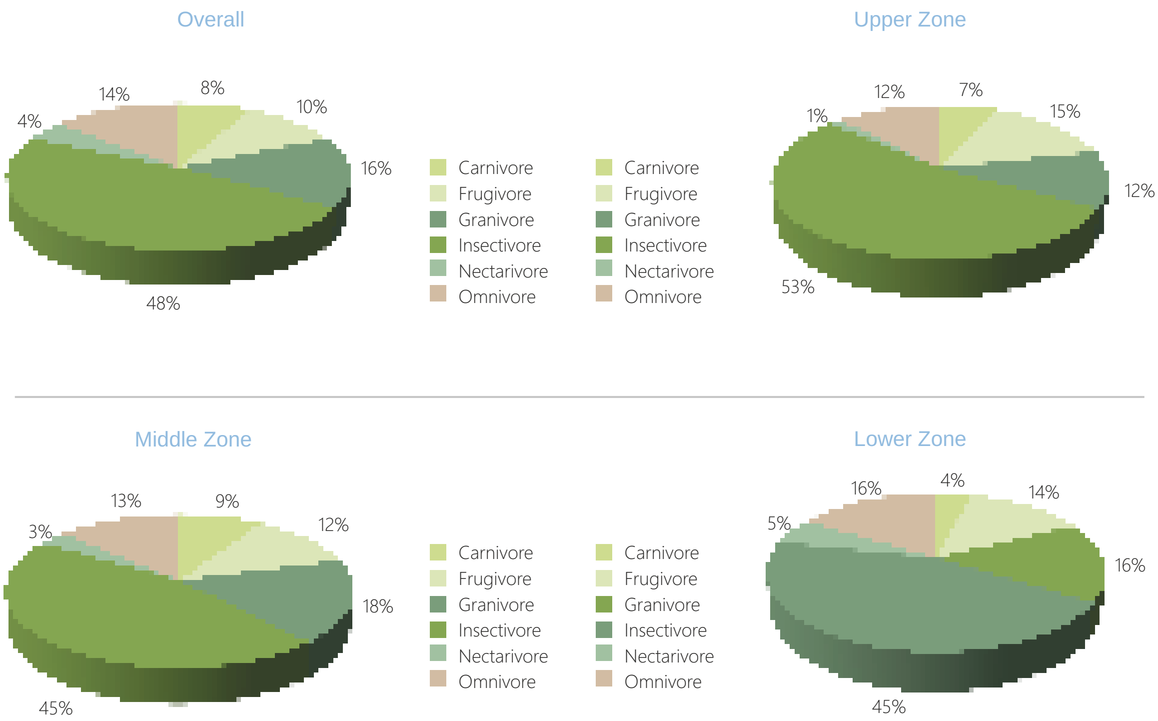


Figure 8.14 Proportion of Terrestrial birds in different trophic guilds in the Upper, Middle and Lower Zone of Godavari River

8.3.9 Distribution of birds

8.3.9.1 Waterbirds and water dependent/associated birds

Assessment of distribution of waterbirds indicated that 32 species were widely distributed in the Godavari River and all were recorded from all the zone of the river. The widely distributed species were White-throated Kingfisher (*Halcyon smyrnensis*), Red-wattled Lapwing (*Vanellus indicus*), Indian Pond-Heron (*Ardeola grayii*), Wire-tailed Swallow (*Hirundo smithii*), Grey Heron (*Ardea cinerea*), River Tern (*Sterna aurantia*), Intermediate Egret (*Ardea intermedia*), Eastern Cattle Egret (*Bubulcus ibis*), Pied Kingfisher (*Ceryle rudis*), Indian Cormorant (*Phalacrocorax fuscicollis*), White-browed Wagtail (*Motacilla maderaspatensis*), Spot-billed Duck (*Anas poecilorhyncha*), Glossy Ibis (*Plegadis falcinellus*), Common Kingfisher (*Alcedo atthis*), Asian Openbill (*Anastomus oscitans*), Little Cormorant (*Microcarbo niger*), Ruddy Shelduck (*Tadorna ferruginea*), Painted Stork (*Mycteria leucocephala*), Purple Heron (*Ardea purpurea*), White-breasted Waterhen (*Amaurornis phoenicurus*), Red-naped Ibis (*Pseudibis papillosa*), Great Cormorant (*Phalacrocorax Cvbo*), Black-winged Stilt (*Himantopus himantopus*), Great Egret (*Ardea alba*), White wagtail (*Motacilla alba*), Streak-throated Swallow (*Petrochelidon fluvicola*), Little Egret (*Egretta garzetta*), Black-bellied Tern (*Sterna acuticauda*), Temminck's Stint (*Calidris temminckii*), Bar-headed Goose (*Anser indicus*) and Northern Pintail (*Anas acuta*).

In total of 19 species had a very narrow distribution and were recorded from only one segment. Among the species with narrow distribution species, Red-rumped Swallow (*Cecropes daurica*), Common Greenshank (*Tringa nebularia*), Common Pochard (*Aythya ferina*), Common Shelduck (*Tadorna tadorna*), Green-winged Teal (*Anas crecca*), Cotton-pygmy Goose (*Nettapus coromandelianus*), Demoiselle Crane (*Anthropoides virgo*), Eurasian Wigeon (*Mareca Penelope*), Greater Flamingo (*Phoenicopterus roseus*), Pheasant-tailed Jacana (*Hydrophasianus chirurgus*) and Red-crested Pochard (*Netta rufina*) were restricted to upper zone. Grey-headed Fish-Eagle (*Icthyophaga ichthyaetus*), Stork-billed Kingfisher (*Pelargopsis capensis*) and Black-crowned Night-Heron (*Nycticorax nycticorax*) were restricted to middle zone and Osprey (*Pandion haliaetus*), Common Merganser (*Mergus merganser*), Striated Heron (*Butorides striata*) and Indian Skimmer (*Rynchops albicollis*) were restricted to lower zone.

8.3.9.2 Terrestrial birds

Assessment of terrestrial birds indicate that 23 species were widely distributed and were recorded from all the zones of the Godavari River. The widely distributed species were Green Bee-eater (*Merops orientalis*), Black Drongo (*Dicrurus macrocercus*), Red-vented Bulbul (*Pycnonotus cafer*), Ashy Prinia (*Prinia socialis*), Laughing Dove (*Spilopelia senegalensis*), Pied Bushchat (*Saxicola caprata*), Purple Sunbird (*Cinnyris asiaticus*), Oriental Magpie-Robin (*Copsychus saularis*), Blyth's Reed Warbler (*Acrocephalus dumetorum*), Indian Robin (*Copsychus fulicatus*), Greater Coucal (*Centropus sinensis*), Long-tailed Shrike (*Lanius schach*), Plain Prinia

Table 8.5 Distribution of birds in Godavari River

Species	Scientific Name	Water Association	Sampling Segment								
			1	2	3	4	5	6	7	8	9
Alexandrine Parakeet	*Psittacula eupatria* T	-	+	-	+	-	+	+	+	-	-
Ashy Prinia	*Prinia socialis*	T	-	+	+	+	+	+	+	+	+
Ashy-crowned Sparrow-Lark	*Eremopterix griseus* T	-	+	+	-	-	+	+	+	-	-
Asian Koel	*Eudynamys scolopaceus*	T	-	+	+	+	+	+	+	+	+
Asian Openbill	*Anastomus oscitans* WB	-	-	-	-	+	+	-	-	-	-
Asian Palm Swift	*Cypsiurus balasiensis* T	-	-	-	+	+	-	-	+	+	+
Asian Pied Starling	*Gracupica contra*	T	-	+	+	-	+	-	+	+	+
Bar-headed Goose	*Anser indicus*	WB	-	-	-	-	-	-	-	-	-
Barn Swallow	*Hirundo rustica*	WAB	+	+	-	+	+	-	-	+	-
Baya Weaver	*Ploceus philippinus* T	-	-	+	-	+	+	-	+	-	-
Bay-backed Shrike	*Lanius vittatus*	T	+	-	-	-	-	-	-	+	-
Black Drongo	*Dicrurus macrocercus* T	+	+	+	+	+	+	+	+	+	+
Black Kite	*Milvus migrans*	T	+	+	+	-	+	+	-	+	+
Black Redstart	*Phoenicurus ochruros* T	-	-	+	-	+	+	+	+	-	+
Black-winged Stilt	*Himantopus himantopus*	WB	-	-	-	-	+	+	+	+	-
Black-bellied Tern	*Sterna acuticauda* WB	-	-	-	-	+	-	-	-	-	-
Black-crowned Night Heron	*Nycticorax nycticorax* WB	-	-	+	+	+	-	+	-	+	+
Black-headed Bunting	*Emberiza melanocephala*	T	-	-	-	-	-	-	-	-	-
Black-headed Cuckooshrike	*Lalage melanoptera* T	-	-	-	-	-	-	-	-	-	-
Black-headed Ibis	*Threskiornis melanocephalus*	WB	-	+	-	-	+	+	+	+	-

(*Prinia inornate*), Purple-rumped sunbird (*Leptocoma zeylonica*), Baya Weaver (*Ploceus philippinus*), Brahminy Starling (*Sturnia pagodarum*), Indian Silverbill (*Euodice malabarica*), Lesser Whitethroat (*Curruca curruca*), Red Avadavat (*Amandava amandava*), Rose-ringed Parakeet (*Pisttacula krameri*), Eurasian Collared-Dove (*Streptopelia decaocto*), Paddyfield Pipit (*Anthus rufulus*) and Yellow-eyed Babbler (*Chrysomma sinense*).

A total of 25 species of birds were with narrow distribution and were recorded from only one segment. The narrowly distributed were Black-headed Bunting (*Emberiza melanocephala*), Blue Rock-Thrush (*Monticola solitarius*), Chestnut-bellied Sandgrouse (*Pterocles exustus*), Common Babbler (*Argya caudata*), Common Chiffchaff (*Phylloscopus collybita*), Eurasian Kestrel (*Falco tinnunculus*), Common Woodshrike (*Tephrodornis pondicerianu*), Crested Bunting (*Emberiza lathami*), Crested Serpent-Eagle (*Spilornis cheela*), India Eagle-Owl (*Bubo bengalensis*), Fulvous-breasted Woodpecker (*Dendrocopos macei*), Golden-fronted Leafbird (*Chloropsis aurifrons*), Greater Flameback (*Chrysocolaptes guttacristatus*), Grey Shrike (*Lanius excubitor*), Indian Cuckoo (*Cuculus Micropterus*), Jungle Bush-Quail (*Perdicula asiatica*), Large Grey Babbler (*Argya malcolmi*), Marshall's Iora (*Aegithina nigrolutea*), Rain Quail (*Coturnix coromandelica*), Singing Bushlark (*Mirafra javanica*), Tawny-bellied Babbler (*Dumetia hyperythra*), Tickell's Blue Flycatcher (*Cyornis tickelliae*), White-eared Bulbul (*Pycnonotus leucotis*), White-eyed Buzzard (*Butastur teesa*) and Yellow-throated Sparrow (*Gymnoris xanthocollis*). (Table 8.5)

Sampling Segment																	
10	11	12	13	14	15	16	17	19	20	21	23	24	25	26	27	28	29
-	-	-	-	-	+	-	-	+	-	+	-	-	-	-	-	-	
+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	+
+	-	-	-	-	-	-	-	+	-	-	+	-	-	+	-	-	
+	+	+	+	+	+	-	-	+	-	-	-	+	-	-	-	+	-
-	-	-	+	-	+	-	+	-	-	+	+	-	-	-	+	-	
-	+	-	-	-	-	-	+	+	+	-	+	+	+	-	-	-	
-	-	+	-	+	+	-	-	+	+	-	+	+	+	-	+	+	-
-	-	-	+	+	+	-	-	-	+	-	+	-	-	-	-	-	-
+	+	+	-	-	+	-	-	-	+	-	-	-	-	-	-	-	-
-	+	+	+	+	+	-	+	-	-	-	+	-	-	-	-	-	
-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
+	+	-	-	-	-	+	-	-	-	+	-	-	+	+	+	+	
+	-	-	+	+	-	-	+	-	-	-	-	-	-	-	-	-	-
+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	+	-	
+	-	-	-	+	-	-	+	-	+	-	+	-	-	-	-	+	-
-	+	-	+	-	-	+	-	+	-	-	+	+	+	+	-	-	
-	+	-	-	-	+	-	-	-	-	-	-	-	-	+	-	-	
-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-
-	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	
-	+	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-

Species	Scientific Name	Water Association	Sampling Segment								
			1	2	3	4	5	6	7	8	9
Black-tailed Godwit	*Limosa limosa*	WB	-	-	-	-	+	-	-	-	-
Black-winged Kite	*Elanus caeruleus*	T	+	+	+	-	+	+	-	+	-
Blue Rock-Thrush	*Monticola solitarius*	T	-	-	-	-	-	-	-	-	-
Blue-faced Malkoha	*Phaenicophaeus viridirostris*	T	-	-	-	-	-	-	-	-	-
Blue-tailed Bee-eater	*Merops philippinus*	WAB	-	-	-	-	-	-	-	-	-
Bluethroat	*Luscinia svecica*	T	-	-	-	-	-	-	-	-	-
Blyth's Reed Warbler	*Acrocephalus dumetorum*	T	-	+	-	+	+	-	-	+	-
Brahminy Starling	*Sturnia pagodarum*	T	-	+	+	+	+	+	-	+	+
Brahminy Kite	*Haliastur indus*	WAB	-	-	-	-	+	+	-	-	+
Brown Crake	*Zapornia akool*	WB	-	-	-	-	+	-	-	+	-
Brown Rock Chat	*Oenanthe fusca*	T	-	+	+	+	-	-	-	+	-
Brown Shrike	*Lanius cristatus*	T	-	-	-	-	-	-	-	-	-
Brown-capped Pygmy Woodpecker	*Yungipicus nanus*	T	-	-	-	-	-	+	-	-	-
Brown-headed Barbet	*Psilopogon zeylanicus*	T	+	+	+	+	+	-	-	-	-
Brown-headed Gull	*Chroicocephalus brunnicephalus*	WB	-	-	-	-	+	-	-	-	-
Caspian Tern	*Hydroprogne caspia*	WB	-	-	-	-	-	-	-	-	-
Changeable Hawk-Eagle	*Nisaetus cirrhatus*	T	-	-	-	-	-	-	-	-	-
Chestnut-bellied Sandgrouse	*Pterocles exustus*	T	-	-	-	-	-	-	-	+	-
Cinereous Tit	*Parus cinereus*	T	-	+	-	+	+	+	-	+	+
Cinnamon Bittern	*Ixobrychus cinnamomeus*	WB	-	-	-	-	+	-	-	-	-
Citrine Wagtail	*Motacilla citreola*	WAB	-	-	-	-	-	+	-	-	-
Clamorous Reed Warbler	*Acrocephalus stentoreus*	T	-	-	-	-	-	+	-	+	-
Common Babbler	*Argya caudata*	T	-	-	-	+	+	-	-	+	-
Common Chiffchaff	*Phylloscopus collybita*	T	-	-	-	-	-	-	-	+	-
Common Greenshank	*Tringa nebularia*	WB	-	+	+	-	+	-	+	-	-
Common Hawk-Cuckoo	*Hierococcyx varius*	T	-	-	-	-	+	+	+	+	-
Common Iora	*Aegithina tiphia*	T	-	-	-	-	-	+	-	+	-
Common Kestrel	*Falco tinnunculus*	T	-	-	-	-	-	-	-	-	-
Common Kingfisher	*Alcedo atthis*	WB	+	+	-	-	+	+	-	+	+
Common merganser	*Mergus merganser*	WB	-	-	-	-	-	-	-	-	-
Common Myna	*Acridotheres tristis*	T	+	+	+	+	+	+	+	+	+
Common Pochard	*Aythya ferina*	WB	-	-	-	-	+	-	-	-	-
Common Redshank	*Tringa totanus*	WB	-	-	-	-	-	+	-	-	-
Common Sandpiper	*Actitis hypoleucos*	WB	+	+	-	-	+	+	-	-	-

Sampling Segment																	
10	11	12	13	14	15	16	17	19	20	21	23	24	25	26	27	28	29
+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	+	+	-	+	+	+	+	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
-	-	-	+	-	-	-	-	+	-	+	-	-	-	-	-	+	+
-	-	-	-	-	-	-	-	+	-	-	-	+	+	+	-	+	-
-	-	-	-	-	-	+	+	+	+	-	+	-	-	-	-	-	-
+	+	+	+	+	+	+	-	+	+	+	+	+	+	+	+	+	-
+	-	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	+	-	-	+	-	+	+	-	-	+	-	-	-	-	-
+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
-	-	-	-	-	-	-	-	-	-	+	+	+	+	+	-	-	-
+	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
-	+	+	+	-	-	-	-	-	-	+	-	-	+	-	+	-	-
-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
-	+	-	-	+	+	-	+	+	+	-	-	+	-	-	-	-	-
-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-	-	-
+	+	-	-	-	+	-	+	+	-	-	+	+	-	-	+	+	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	-	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Species	Scientific Name	Water Association	Sampling Segment								
			1	2	3	4	5	6	7	8	9
Common Shelduck	*Tadorna tadorna*	WB	-	+	-	-	-	-	-	-	-
Siberian Stonechat	*Saxicola maurus*	T	-	+	-	-	+	-	-	-	-
Common Tailorbird	*Orthotomus sutorius*	T	-	+	+	+	+	+	+	+	+
Common Teal	*Anas crecca*	WB	-	+	-	-	-	-	-	-	-
Common Woodshrike	*Tephrodornis pondicerianus*	T	-	-	-	-	-	-	-	-	-
Coppersmith Barbet	*Psilopogon haemacephalus*	T	-	+	+	+	+	+	+	+	+
Cotton Pygmy-Goose	*Nettapus coromandelianus*	WB	-	+	-	-	-	-	-	-	-
Crested Serpent-Eagle	*Spilornis cheela*	T	-	-	+	-	+	+	-	-	-
Crested Bunting	*Emberiza lathami*	T	-	-	-	-	-	+	-	-	-
Demoiselle Crane	*Grus virgo*	WB	-	+	-	-	-	-	-	-	-
Desert Wheatear	*Oenanthe deserti*	T	-	-	-	-	-	+	-	-	-
Dusky Crag-Martin	*Ptyonoprogne concolor*	T	-	-	-	+	-	+	-	+	-
Eastern Cattle Egret	*Bubulcus coromandus*	WB	+	+	+	+	+	+	+	+	+
Eastern Yellow Wagtail	*Motacilla tschutschensis*	WAB	-	-	-	-	+	+	-	+	+
Eurasian Collared-Dove	*Streptopelia decaocto*	T	-	+	+	+	+	+	-	+	-
Eurasian Coot	*Fulica atra*	WB	-	+	-	+	+	+	-	+	-
Eurasian Hoopoe	*Upupa epops*	T	-	-	+	-	+	+	-	-	-
Eurasian Oystercatcher	*Haematopus ostralegus*	WB	-	-	-	-	-	-	-	-	-
Eurasian Spoonbill	*Platalea leucorodia*	WB	-	-	-	-	-	+	-	-	-
Eurasian Wigeon	*Mareca penelope*	WB	-	+	-	-	-	-	-	-	-
Glossy Ibis	*Plegadis falcinellus*	WB	+	+	-	-	+	+	-	+	-
Golden-fronted Leafbird	*Chloropsis aurifrons*	T	-	-	-	-	-	-	-	-	-
Grey-breasted Prinia	*Prinia hodgsonii*	T	-	-	+	-	-	-	-	-	+
Great Cormorant	*Phalacrocorax carbo*	WB	+	+	+	+	+	+	+	+	+
Great Egret	*Ardea alba*	WB	-	+	-	-	+	+	+	-	-
Great Knot	*Calidris tenuirostris*	WB	-	-	-	-	-	-	-	-	-
Greater Coucal	*Centropus sinensis*	T	+	-	+	-	+	+	+	+	+
Greater Flameback	*Chrysocolaptes guttacristatus*	T	-	-	-	-	-	-	-	-	-
Greater Flamingo	*Phoenicopterus roseus*	WB	-	-	-	-	-	-	-	-	-
Greater Painted-Snipe	*Rostratula benghalensis*	WB	-	-	-	-	-	-	-	-	+
Green Bee-eater	*Merops orientalis*	T	+	+	+	+	+	+	-	+	+
Green Sandpiper	*Tringa ochropus*	WB	-	-	+	+	+	-	-	+	-
Greenish Warbler	*Phylloscopus trochiloides*	T	-	-	-	-	-	-	-	-	-
Grey Francolin	*Ortygornis pondicerianus*	T	-	-	-	-	+	+	-	-	+

Sampling Segment																	
10	11	12	13	14	15	16	17	19	20	21	23	24	25	26	27	28	29
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
+	+	+	+	+	+	+	-	-	-	+	-	-	-	+	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	+	+	+	-	+	+	-	-	+	-	-	-	-	-	+	+	+
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	+	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
+	+	+	+	+	+	+	+	+	-	-	+	-	+	-	-	+	+
+	+	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-
-	+	+	+	+	+	-	+	-	+	-	-	-	-	-	-	-	+
+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	+	-	+	+	-	+	+	-	+	+	+	-	-	-	+
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
-	-	-	+	+	+	-	-	-	-	+	-	-	+	-	-	-	-
-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	-
-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	+	+	-	+	+	-	-	+	-	-	-	+	+	-	-	+	-
+	+	-	-	+	+	-	-	-	-	-	-	-	-	-	+	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
+	-	+	+	+	+	-	-	+	-	-	-	+	+	+	-	+	+
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-
-	-	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-

Species	Scientific Name	Water Association	Sampling Segment								
			1	2	3	4	5	6	7	8	9
Grey Heron	*Ardea cinerea*	WB	-	+	+	+	+	+	+	+	-
Grey Plover	*Pluvialis squatarola*	WB	-	-	-	-	-	-	-	-	-
Great Grey Shrike	*Lanius excubitor*	T	-	-	+	-	-	-	-	-	-
Grey Wagtail	*Motacilla cinerea*	WAB	-	+	-	+	+	+	-	+	+
Grey-headed Fish-Eagle	*Icthyophaga ichthyaetus*	WAB	-	-	-	-	-	-	-	-	-
Grey-headed Swamphen	*Porphyrio poliocephalus*	WB	-	+	-	+	+	-	-	-	+
Gull-billed Tern	*Gelochelidon nilotica*	WB	-	-	-	-	-	-	-	-	-
House Crow	*Corvus splendens*	T	-	+	-	+	+	+	+	+	+
House Sparrow	*Passer domesticus*	T	+	+	+	+	+	+	+	-	+
Hume's Warbler	*Phylloscopus humei*	T	-	+	-	+	-	+	-	-	-
Indian Cormorant	*Phalacrocorax fuscicollis*	WB	+	+	-	-	+	+	-	-	-
Indian Cuckoo	*Cuculus micropterus*	T	-	-	-	-	-	-	-	-	-
Indian Golden Oriole	*Oriolus kundoo*	T	-	-	+	-	+	-	-	+	-
Indian Grey Hornbill	*Ocyceros birostris*	T	-	-	-	-	-	+	+	-	-
Indian Peafowl	*Pavo cristatus*	T	+	+	+	+	+	-	-	+	-
Indian Pond-Heron	*Ardeola grayii*	WB	+	+	+	+	+	+	+	+	+
Indian Robin	*Copsychus fulicatus*	T	-	+	+	+	+	+	-	+	+
Indian Roller	*Coracias benghalensis*	T	-	+	+	+	-	-	-	-	-
Indian Silverbill	*Euodice malabarica*	T	-	+	-	-	-	+	-	-	-
Indian Skimmer	*Rynchops albicollis*	WB	-	-	-	-	-	-	-	-	-
Indian Spot-billed Duck	*Anas poecilorhyncha*	WB	-	+	-	-	+	+	-	+	-
Indian White-eye	*Zosterops palpebrosus*	T	+	+	+	+	+	-	-	+	-
Intermediate Egret	*Ardea intermedia*	WB	+	-	+	-	+	-	-	+	-
Jungle Babbler	*Argya striata*	T	+	-	+	-	-	+	-	+	-
Jungle Bush-Quail	*Perdicula asiatica*	T	-	-	-	-	+	-	-	-	-
Jungle Myna	*Acridotheres fuscus*	T	-	+	-	+	+	-	-	-	-
Jungle Prinia	*Prinia sylvatica*	T	-	-	-	-	-	+	-	+	-
Kentish Plover	*Anarhynchus alexandrinus*	WB	-	-	-	-	+	-	-	-	-
Knob-billed Duck	*Sarkidiornis melanotos*	WB	-	-	-	-	-	-	-	-	-
Large-billed Crow	*Corvus macrorhynchos*	T	+	+	+	+	+	+	+	-	-
Large Grey Babbler	*Argya malcolmi*	T	-	-	-	-	-	-	-	+	-
Laughing Dove	*Spilopelia senegalensis*	T	-	+	+	+	+	+	+	+	+
Lesser Crested Tern	*Thalasseus bengalensis*	WB	-	-	-	-	-	-	-	-	-
Tibetan Sand-Plover	*Anarhynchus atrifrons*	WB	-	-	-	-	-	-	-	-	-

Sampling Segment																	
10	11	12	13	14	15	16	17	19	20	21	23	24	25	26	27	28	29
+	+	+	+	+	+	-	+	+	-	-	-	+	-	-	-	+	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	+	+	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
+	+	-	-	-	+	-	-	-	-	-	+	+	-	-	+	+	-
+	+	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	+
-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	+	+	+	-	+	+	+	+	+	+	-	+	+	-	-	-	-
-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
+	+	+	-	-	-	-	-	-	-	+	-	-	-	+	+	+	-
-	+	-	-	-	-	+	-	+	-	-	-	-	-	-	-	+	-
-	-	-	-	+	+	+	+	-	-	-	-	-	-	-	-	-	-
+	+	+	+	+	+	+	+	+	-	-	+	+	+	-	+	+	+
+	+	-	+	+	+	+	+	+	+	+	+	-	+	-	-	+	-
-	-	-	+	+	-	+	+	-	-	-	-	-	-	-	-	-	-
-	-	-	-	+	+	+	+	+	+	+	-	+	-	-	-	+	-
-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+
+	+	-	+	+	-	+	+	-	+	-	-	-	-	+	-	-	-
+	+	+	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
-	+	+	+	+	+	+	+	+	-	-	-	-	+	+	+	+	+
+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	+	+	-	-	+	-	+	+	-	-	-	-	-	-	-	-
-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	+	-	-	+	-	-	-	-	-	-	-	-
-	-	+	-	-	-	-	-	-	-	-	+	-	-	+	+	+	+
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+

Species	Scientific Name	Water Association	Sampling Segment								
			1	2	3	4	5	6	7	8	9
Lesser Whistling-Duck	*Dendrocygna javanica*	WB	-	-	-	-	-	-	-	-	-
Lesser Whitethroat	*Curruca curruca*	T	-	-	-	-	-	+	-	+	-
Little Cormorant	*Microcarbo niger*	WB	-	-	+	-	+	+	+	-	-
Little Egret	*Egretta garzetta*	WB	-	-	-	-	+	+	+	+	-
Little Grebe	*Tachybaptus ruficollis*	WB	-	-	-	-	+	+	+	-	-
Little Ringed Plover	*Charadrius dubius*	WB	-	-	-	-	+	+	-	-	-
Little Stint	*Calidris minuta*	WB	-	-	-	-	+	-	-	-	-
Little Swift	*Apus affinis*	T	-	-	-	-	+	+	-	-	+
Little Tern	*Sternula albifrons*	WB	-	-	-	-	+	-	-	-	-
Long-tailed Shrike	*Lanius schach*	T	-	+	+	+	+	+	+	+	-
Marshall's Iora	*Aegithina nigrolutea*	T	-	-	-	-	-	-	-	-	-
Northern Pintail	*Anas acuta*	WB	-	-	-	-	-	-	-	-	-
Northern Shoveler	*Spatula clypeata*	WB	-	+	-	-	+	-	-	-	-
Orange-headed Thrush	*Geokichla citrina*	T	-	-	-	-	-	-	-	-	-
Oriental Darter	*Anhinga melanogaster*	WB	-	-	-	-	-	-	-	-	-
Oriental Honey-Buzzard	*Pernis ptilorhynchus*	T	-	-	+	-	-	+	-	+	+
Oriental Magpie-Robin	*Copsychus saularis*	T	-	+	+	+	+	+	+	+	+
Osprey	*Pandion haliaetus*	WAB	-	-	-	-	-	-	-	-	-
Paddyfield Pipit	*Anthus rufulus*	T	-	+	+	+	-	+	-	+	+
Painted Stork	*Mycteria leucocephala*	WB	-	+	-	-	+	+	-	-	-
Pale-billed Flowerpecker	*Dicaeum erythrorhynchos*	T	-	-	+	-	-	+	-	-	+
Pallas's Gull	*Ichthyaetus ichthyaetus*	WB	-	-	-	-	+	+	-	-	-
Pheasant-tailed Jacana	*Hydrophasianus chirurgus*	WB	-	+	-	-	+	-	-	-	-
Pied Bushchat	*Saxicola caprata*	T	-	+	+	+	+	+	+	+	+
Pied Kingfisher	*Ceryle rudis*	WAB	-	-	+	-	+	+	-	-	-
Plain Prinia	*Prinia inornata*	T	-	+	+	-	-	-	-	-	-
Plum-headed Parakeet	*Psittacula cyanocephala*	T	-	-	-	-	-	+	+	-	-
Purple Heron	*Ardea purpurea*	WB	-	+	-	-	+	+	-	+	+
Purple Sunbird	*Cinnyris asiaticus*	T	+	+	+	+	+	+	+	+	+
Purple-rumped Sunbird	*Leptocoma zeylonica*	T	-	-	-	-	+	+	+	+	+
Rain Quail	*Coturnix coromandelica*	T	-	-	-	-	-	-	-	-	-
Red Munia	*Amandava amandava*	T	-	-	+	-	+	-	-	+	-
Red Collared-Dove	*Streptopelia tranquebarica*	T	-	+	-	-	-	-	-	+	-
Red-crested Pochard	*Netta rufina*	WB	-	+	-	-	-	-	-	-	-

	Sampling Segment																	
	10	11	12	13	14	15	16	17	19	20	21	23	24	25	26	27	28	29
	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	+	-	-
	-	-	+	+	+	+	-	-	+	-	+	+	-	+	+	-	-	-
	-	+	-	-	-	+	+	+	-	+	-	+	+	+	-	-	+	-
	+	+	-	-	+	+	-	+	-	-	-	+	-	+	+	-	-	-
	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
	+	+	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
	-	+	+	+	+	-	-	+	+	+	-	-	-	+	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
	-	-	-	-	+	-	-	+	-	+	-	-	+	-	-	-	+	+
	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
	-	-	-	-	+	-	+	+	-	-	-	-	-	-	-	+	-	-
	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-
	+	-	-	-	-	-	+	+	+	-	-	+	+	+	+	+	+	+
	-	-	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-
	+	-	-	-	-	-	-	-	-	-	+	-	-	-	+	+	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	+	+	+	-	+	+	+	+	+	+	+	+	+	-	+	-	-	-
	+	-	+	+	+	-	+	+	+	+	-	+	-	+	-	+	+	-
	+	+	+	+	+	+	+	+	+	+	-	+	+	-	+	-	-	-
	-	+	-	-	+	-	+	+	-	+	+	-	-	+	-	-	-	-
	-	+	+	-	-	-	+	+	+	-	-	-	-	-	-	-	-	-
	+	+	+	-	+	+	+	+	+	-	+	+	+	+	+	+	-	+
	-	+	+	+	+	+	-	-	+	+	+	+	+	+	+	+	+	+
	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
	-	-	-	+	+	-	+	+	+	+	-	+	+	+	-	-	-	-
	-	-	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Species	Scientific Name	Water Association	Sampling Segment								
			1	2	3	4	5	6	7	8	9
Red-naped Ibis	*Pseudibis papillosa*	WB	-	-	+	-	+	+	-	+	+
Red-vented Bulbul	*Pycnonotus cafer*	T	+	+	+	+	+	+	+	+	+
Red-wattled Lapwing	*Vanellus indicus*	WB	+	+	+	-	+	+	-	+	+
Red-whiskered Bulbul	*Pycnonotus jocosus*	T	-	-	-	-	-	-	-	-	-
Red-rumped Swallow	*Cecropis daurica*	WAB	-	+	+	-	+	-	+	+	+
River Lapwing	*Vanellus duvaucelii*	WB	-	-	-	-	-	-	-	-	-
River Tern	*Sterna aurantia*	WB	-	-	+	-	+	+	-	+	-
Indian Eagle-Owl	*Bubo bengalensis*	T	-	-	-	-	-	-	-	-	-
Rock Pigeon	*Columba livia*	T	+	+	+	+	+	-	+	+	+
Rose-ringed Parakeet	*Psittacula krameri*	T	+	+	+	+	+	+	+	+	-
Rosy Starling	*Pastor roseus*	T	-	+	-	+	+	-	-	-	-
Ruddy Shelduck	*Tadorna ferruginea*	WB	-	+	-	-	+	+	-	-	-
Ruddy Turnstone	*Arenaria interpres*	WB	-	-	-	-	-	-	-	-	-
Rufous-tailed Lark	*Ammomanes phoenicura*	T	-	+	-	+	-	+	-	+	+
Rufous Treepie	*Dendrocitta vagabunda*	T	-	-	-	-	-	-	-	-	-
Small Minivet	*Pericrocotus cinnamomeus*	T	-	-	-	-	+	+	-	-	-
Scaly-breasted Munia	*Lonchura punctulata*	T	-	-	-	-	-	-	-	-	-
Shikra	*Accipiter badius*	T	-	-	+	-	+	-	-	+	-
Short-toed Snake-Eagle	*Circaetus gallicus*	T	-	-	-	-	-	+	-	-	-
Singing Bushlark	*Mirafra javanica*	T	-	-	-	-	-	-	-	-	-
Small Pratincole	*Glareola lactea*	WB	-	-	-	-	-	+	-	-	-
Spot-breasted Fantail	*Rhipidura albogularis*	T	-	-	-	-	+	+	-	-	-
Spotted Dove	*Spilopelia chinensis*	T	+	-	-	-	-	-	-	-	-
Spotted Owlet	*Athene brama*	T	-	-	+	-	-	+	-	-	-
Stork-billed Kingfisher	*Pelargopsis capensis*	WAB	-	-	-	-	-	-	-	-	-
Streak-throated Swallow	*Petrochelidon fluvicola*	WAB	-	-	+	-	-	+	-	+	+
Striated Heron	*Butorides striata*	WB	-	-	-	-	-	-	-	+	-
Tawny-bellied Babbler	*Dumetia hyperythra*	T	-	-	-	-	-	-	-	-	-
Temminck's Stint	*Calidris temminckii*	WB	-	-	-	-	+	+	-	+	-
Terek Sandpiper	*Xenus cinereus*	WB	-	-	-	-	-	-	-	-	-
Thick-billed Flowerpecker	*Dicaeum agile*	T	-	-	-	-	-	+	-	+	-
Tickell's Blue Flycatcher	*Cyornis tickelliae*	T	-	-	-	-	-	-	-	-	-
Tricoloured Munia	*Lonchura malacca*	T	-	+	-	-	-	-	-	-	-
Western Marsh Harrier	*Circus aeruginosus*	WAB	-	+	-	-	-	+	-	-	-

	Sampling Segment																	
	10	11	12	13	14	15	16	17	19	20	21	23	24	25	26	27	28	29
	+	+	-	+	+	-	+	-	-	-	-	-	-	-	+	-	+	-
	-	-	+	+	+	-	+	+	+	+	+	+	+	+	+	+	+	+
	+	+	+	+	+	-	+	+	+	+	+	+	+	+	-	+	+	+
	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-
	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	+	+	-	+	-	-	-
	-	-	+	+	+	+	+	+	-	+	-	-	+	-	-	+	+	-
	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
	+	-	+	-	+	+	-	-	-	-	-	-	-	-	-	-	-	+
	+	+	-	-	-	-	+	+	+	-	+	+	-	+	-	-	+	+
	-	-	-	-	+	+	-	-	+	-	-	+	-	-	-	-	-	-
	-	-	-	-	+	-	-	+	-	+	-	-	+	+	+	+	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
	+	+	+	+	+	+	+	+	-	+	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	+	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	+	+	-	+	-	+	+	+	+	-	-	-	-
	-	+	+	+	-	+	-	-	+	-	-	+	-	-	+	-	+	-
	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	+	-	+	-	-	-	+	+	-
	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	+	-	-	+	-	-	-	+	-	-	+	-	-	-	-
	-	-	-	-	+	-	-	+	-	-	-	-	-	-	-	+	-	-
	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	+	-	-	-	-	+	+	-	-	-	+	-	-	-	-
	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	+	-	+	-	-	-	+	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+
	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	+	-	-
	-	-	-	-	-	-	+	+	+	+	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Species	Scientific Name	Water Association	Sampling Segment								
			1	2	3	4	5	6	7	8	9
Western Reef-Egret	*Egretta gularis*	WB	-	-	-	-	-	-	-	-	-
Whiskered Tern	*Chlidonias hybrida*	WB	-	+	-	-	-	-	-	-	-
White-bellied Drongo	*Dicrurus caerulescens*	T	-	-	-	-	+	-	-	-	-
White-breasted Waterhen	*Amaurornis phoenicurus*	WB	+	+	+	-	+	+	-	+	-
White-browed Fantail	*Rhipidura aureola*	T	+	-	-	-	-	-	-	-	-
White-browed Wagtail	*Motacilla maderaspatensis*	WAB	-	-	+	-	-	-	-	-	-
White-eyed Buzzard	*Butastur teesa*	T	+	-	-	-	-	-	-	-	-
White Wagtail	*Motacilla alba*	WAB	-	+	+	+	+	+	+	+	+
White-browed Bulbul	*Pycnonotus luteolus*	T	-	+	-	+	+	+	-	+	-
White-throated Kingfisher	*Halcyon smyrnensis*	WAB	-	-	-	-	-	-	-	-	-
Wire-tailed Swallow	*Hirundo smithii*	WAB	-	-	-	-	-	-	-	-	-
Wood Sandpiper	*Tringa glareola*	WB	+	+	+	-	-	+	+	+	+
Woolly-necked Stork	*Ciconia episcopus*	WB	-	+	-	-	+	+	-	+	+
Yellow-billed Babbler	*Argya affinis*	T	-	-	-	-	-	-	-	-	-
Yellow-footed Green-Pigeon	*Treron phoenicopterus*	T	-	-	-	-	-	+	-	+	-
Yellow-throated Sparrow	*Gymnoris xanthocollis*	T	-	-	-	-	-	-	-	-	-
Yellow-wattled Lapwing	*Vanellus malabaricus*	WB	+	-	-	-	-	+	-	-	-
Yellow-crowned Woodpecker	*Leiopicus mahrattensis*	T	-	-	-	-	-	-	-	-	-
Yellow-eyed Babbler	*Chrysomma sinense*	T	-	+	-	+	+	-	-	-	-
Zitting Cisticola	*Cisticola juncidis*	T	-	-	-	-	-	-	-	+	-

T=Terrestrial, WB=Waterbird, WAB= Water Dependent/Associated Birds

8.3.10 Environmental variable influencing avifauna abundance

We used Canonical Corresponding Analysis (CCA) to determine the factors that affected bird assemblage. CCA results revealed significant relationships between environmental variables and waterbird communities. Results of CCA revealed that the total variance explained collectively by first and second axes was 42% and CCA1 and CCA2 explained 25% and 17% of the variance respectively. Axis 1 indicated turbidity was positively associated to waterbirds assemblages, Axis 2 suggested that human settlement and pH positively influences on waterbirds, while the presence of cattle, depth and water temperature negatively affects the waterbirds assemblages. The results of the CCA analysis computed are highlighted in the Table 8.6.

	Sampling Segment																	
	10	11	12	13	14	15	16	17	19	20	21	23	24	25	26	27	28	29
	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+
	-	-	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-
	-	-	-	+	-	+	-	-	+	-	+	+	+	+	+	+	-	-
	-	-	+	+	-	+	-	-	+	-	+	-	-	-	+	-	-	-
	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	+	+	+	-	+	+	+	+	+	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-	-
	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	+	+	+	+	+	+	+	+	-	-	-	-	-	-	-	+
	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	+	-	+	-	+	+	-	-	-	-	-	-	-	-	-	-
	-	-	+	+	+	+	+	+	+	-	-	-	-	+	-	-	-	-
	-	-	-	+	-	-	-	-	-	-	+	-	-	-	-	-	-	-
	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	+	-	-	-	+	+	+	-	+	-
	+	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 8.6 Result of Canonical Correspondence Analysis for the waterbirds and environmental parameters of Godavari River

Components	Axis 1	Axis 2	Axis 3
Eigenvalues	0.84	0.56	0.53
Proportion Explained	0.25	0.17	0.15
Cumulative Proportion	0.25	0.42	0.58
Aquatic vegetation extraction (AVE)	-0.39	-0.17	0.04
Fishing boats (FB)	0.39	0.33	-0.29
Fishing net (FN)	0.06	0.17	0.33
Ferry boat (FRB)	-0.19	0.18	0.09
Human settlement (HS)	-0.13	0.78	0.15
Human presence (HP)	-0.17	-0.15	0.13
Cattle grazing (CG)	-0.30	-0.64	-0.45
Domestic waste (DM)	-0.04	0.15	0.07
Industrial outlets (IO)	0.39	0.46	0.04
Ferry ghats (FG)	-0.33	0.06	0.13
Width (WID)	0.18	0.34	-0.10
Depth (DP)	-0.11	-0.52	-0.45
Turbidity (TUR)	0.89	0.26	-0.14
PH	-0.10	0.51	-0.47
Water temperature (WT)	-0.21	-0.45	-0.13

8.3.11 Habitat suitability and Stretches of Conservation Priority

A total of 954 km stretch including 572 km in the upper zone, 234 km in the middle zone and 148 km in the lower zone of the Godavari River was found suitable for waterbirds and water dependent/associated species (Table 8.7, Figure 8.16, 8.17 & 8.18). Table 8.7 shows the habitat suitability stretches for waterbirds and water dependent/associated bird species in the upper, middle and lower zones of the Godavari River. Of the total suitability stretches of Godavari River, 198 km falls under Wildlife Sanctuary and National Park, while remaining area is in unprotected area of the river (Table 8.8). All the suitable stretches in the river falls in the states of Maharashtra, Telangana and Andhra Pradesh (Table 8.9).

In the upper zone, stretches of conservation priority were observed from Talwade to Gangapur Dam (17 km), Jaikwadi WLS (11 km), Banegaon to Dakupinpri (42 km) and Dewalgaon to Wahegaon (56 km), In the middle zone, stretches from Sangameshwar temple Sangam to Pushkar Bathing Ghat (11 km), Narsinghpur to Gondeserial (12 km), Lanja Madugu Sivaram WLS (3.5 km), and in the lower zone Kaleshwaram to Edapally (9 km), Somnoor to Dammur (3 km) and Papikonda NP (22 km) were the stretches of conservation priority (Table 8.9).

Table 8.7 Suitable stretch for Conservation of water and water dependent/ associated birds in Godavari River

River zone	Total zone length (km)	High suitable (km)	Moderate suitable (km)	Low suitable (km)	Total suitability (km)
Upper zone	691	149	309	114	572
Middle zone	318	21	117	96	234
Lower zone	453	32	70	46	148
Total length (km)	**1462**	**202**	**496**	**256**	**954**

Table 8.8 Suitable stretches for Conservation of water and water dependent/ associated birds under protected region

Protected Area	Stretch of Godawari River under Protected Area (km)	Suitable habitat stretches of birds under Protected Area (km)
Jaikwadi WLS	74	70
Lanja Madugu Sivaram WLS	17	16
Pranahita WLS	3	3
Eturnagaram WLS	58	22
Papikonda NP	46	42
Total length (km)	**198**	**153**

Table 8.9: Location of suitable stretches for water bird and water associated birds in Godavari River

River zone	Suitable stretches (km)	GPS Location Start Location	End Location	Location	District	State
Upper Zone	17	73.5668E 19.9783N	73.6851E 20.0396N	Talwade to Gangapur Dam	Nashik	Maharashtra
	11	74.8262E 19.6671N	74.9106E 19.6482N	Jaikwadi WLS	Ahmed Nagar & Aurangabad	Maharashtra
	42	76.2558E 19.2531N	76.4721E 19.0957N	Banegaon to Dakupinpri	Beed & Prabhani	Maharashtra
	56	76.8989E 19.0642N	77.2016E 19.1053N	Dewalgaon to Wahegaon	Prabhani, Hingoli & Nanded	Maharashtra
Middle Zone	11	77.8633E 18.8253N	77.9635E 18.8668N	Sangameshwar temple Sangam to Pushkar Bathing Ghat	Nanded, Nijamabad & Nirmal	Maharashtra & Telangana
	12	78.8086 E 19.0515 N	78.9185 E 19.0406 N	Narsinghpur to Gondeserial	Nirmal	Telangana
	3.5	79.7059E 18.6822N	79.7392E 18.6864N	Lanja Madugu Sivaram WLS	Peddapalli I & Mancheria	Telangana
Lower Zone	9	79.9061E 18.8189N	79.9912E 18.7576N	Kaleshwaram to Edapally	Jayashankar	Telangana
	3	80.2766E 18.7282N	80.3004E 18.7030N	Somnoor to Dammur	Jayashankar	Telangana
	22	81.4191E 17.4665N	81.6082E 17.3716N	Papikonda NP	East & West Godavari	Andhra Pradesh

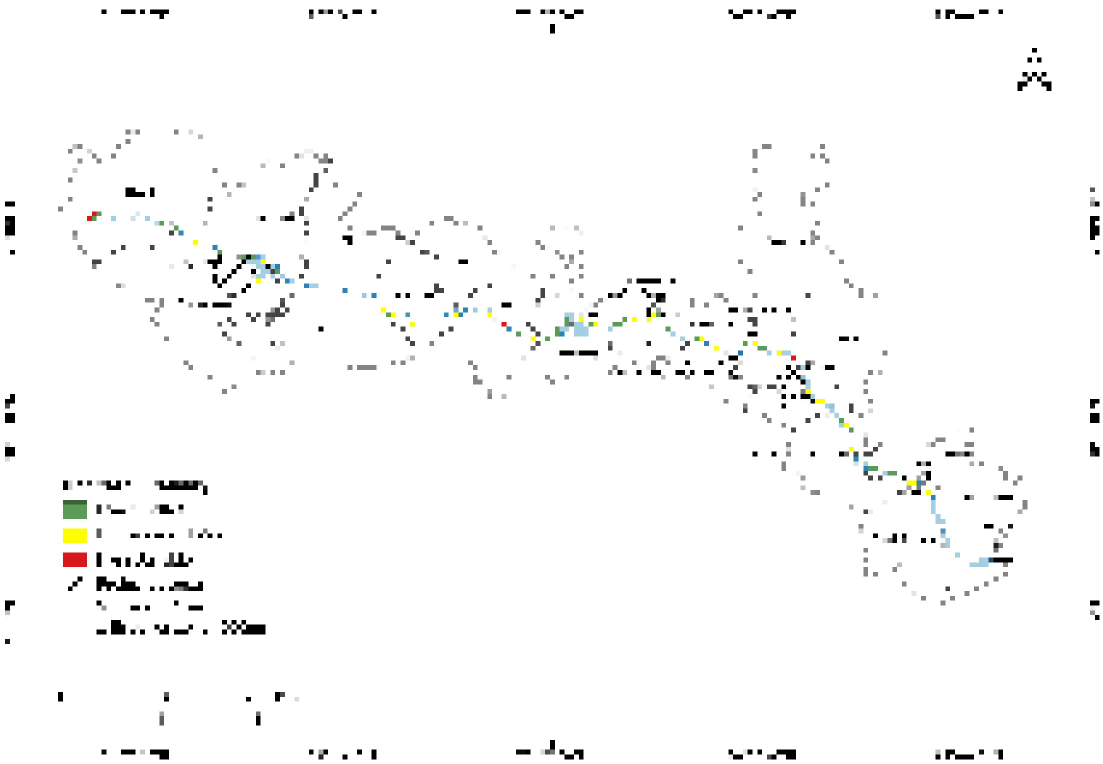


Figure 8.15
Stretches of conservation priority for water and water dependent/ associated birds along the Godavari River, India

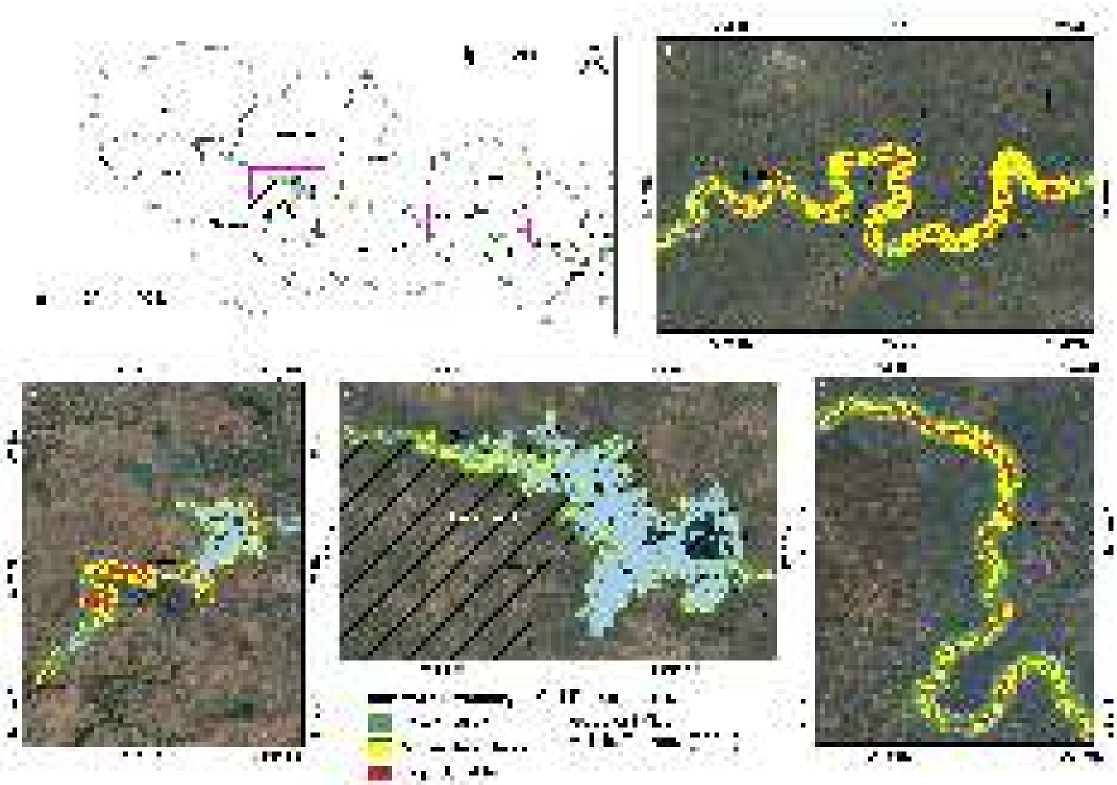


Figure 8.16
Stretches of conservation priority of water and water dependent/ associated birds in the upper zone of Godavari River

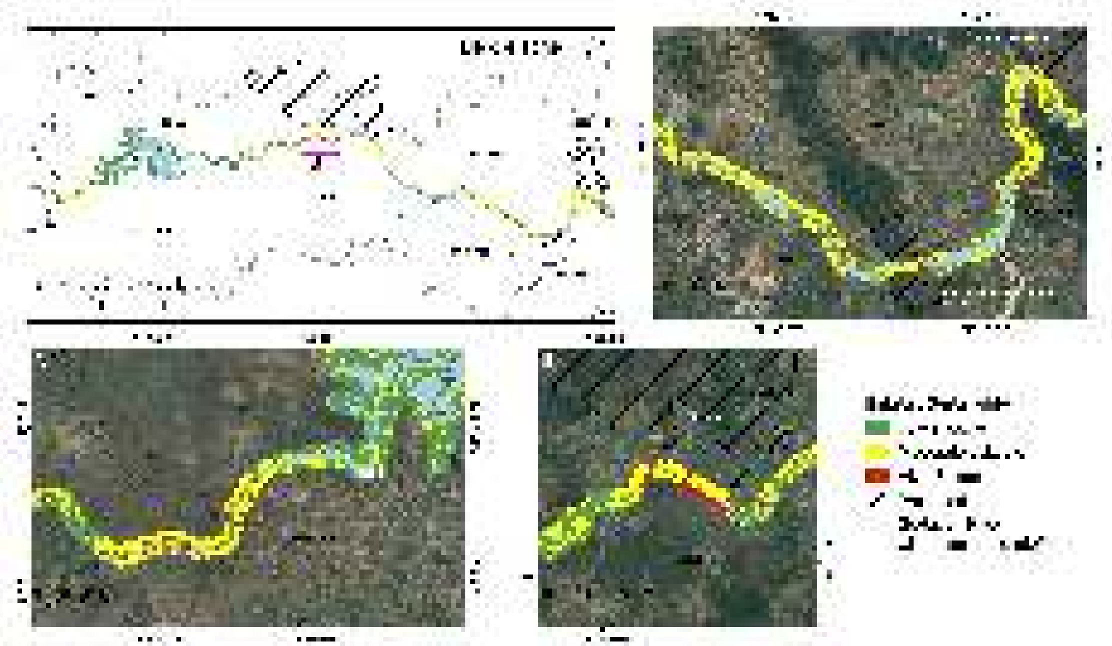


Figure 8.17 Stretches of conservation priority of the water and water dependent/ associated birds in the middle zone of the Godavari River

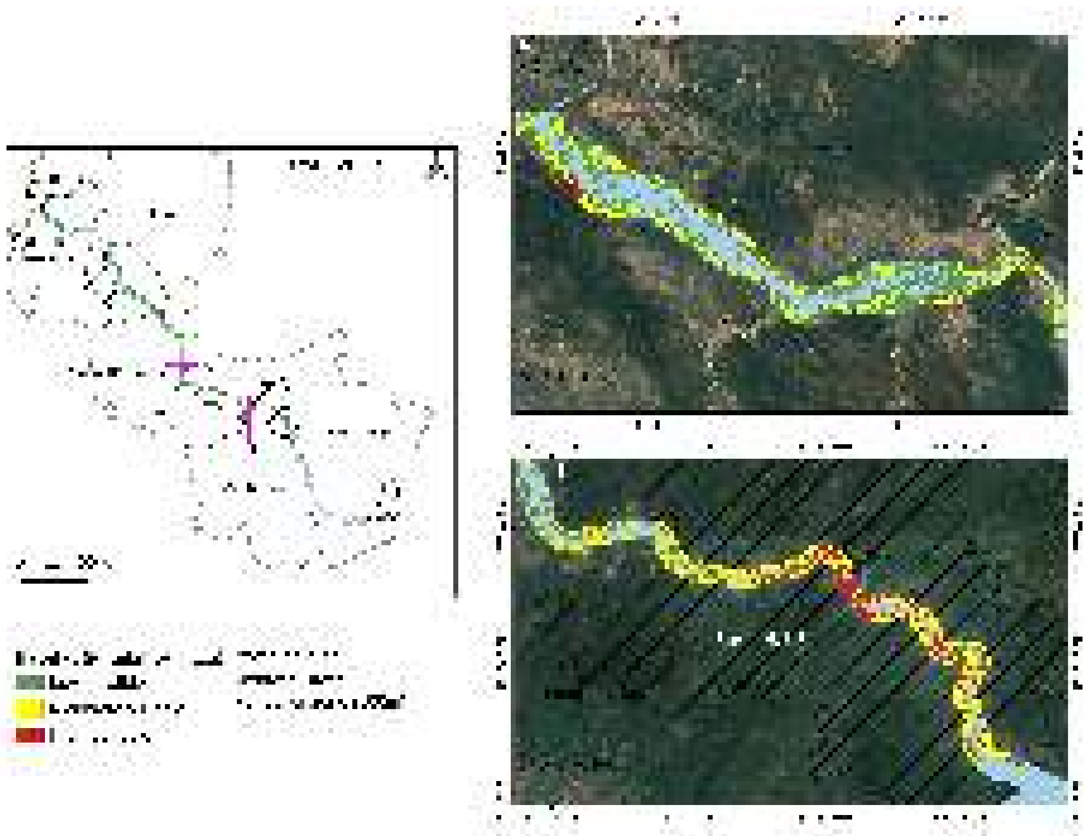


Figure 8.18 Stretches of conservation priority of the water and water dependent/ associated birds in the lower zone of the Godavari River

8.4 Discussion

Our survey highlights presence of 210 different species of birds at an overall diversity of 4.16 in the Godavari River. The richness of the birds in the Godavari River accounted for 54.68% bird species recorded in the Godavari basin (NRCD-WII, 2022), 31.48% bird species of state of Maharashtra (667 bird species, Avi base - The World Bird Database) and 15.39% of the total bird species recorded in the Indian subcontinent (Praveen and Jaypal, 2024). In Addition, the number of species recorded in the Godavari River was higher than various studies conducted in in the Godavari basin (Chavan et al., 2012; Balkhande et al., 2014; Balkhande et al., 2017; Pawar et al., 2019 and Ray et al., 2020). Richness of waterbirds in the Godavari River was found higher than the Periyar Lake (David et al., 2022), Mahanadi River (Jyethi et al., 2021), Barna Reservoir in Narmada River basin (Balapure et al., 2013), Kalpa Wetland, Assam (Das et al., 2014). However, the richness of birds was lower than the Gosekhurd region of Godavari basin and East Godavari River estuarine ecosystem (Sathiyaselvam and Sredhar, 2015; Patil et al., 2019). The lower species richness in the Godavari River in comparison to the other sites in Godavari could be due to the protection provided by Umred Khahadia Wildlife Sanctuary, high forest cover and presence of deep-water bodies which support terrestrial birds and ducks and other deep water preferred species.

Additionally, the richness of water and water dependent/associated birds was lower compared to certain studies conducted in Ganga River (NMCG-WII, 2019) and upper stretch of Ganga River (Vasudeva et al., 2020). This could be related to the protection offered to the various segments of the Ganga River in the form of Important Bird Area (IBA) sites (Narora), Ramsar site (Haidarpur wetland) and wildlife sanctuary (Hastinapur sanctuary).

Family Anatidae was the dominant family among the waterbirds in the Godavari River. Our results are in line with Chavan et al. (2012) who highlighted the dominance of the Anatidae family in the Godavari River basin. The dominance of Anatidae is a common trend in aquatic ecosystems and has been recorded in many studies in similar ecosystems (Dhakate et al., 2008; Kumar and Gupta, 2009; Tak et al., 2010; Bhattacharjee and Bargali, 2013; Ahmed et al., 2019). The dominance of the Anatidae family could be related to the presence of several protected areas along the river. The presence of these protected areas along the river provides the necessary protection to these waterbirds. Members of the Anatidae family usually inhabit a variety of water bodies, such as lakes, rivers, marshes and other habitats. The diet of these species predominantly consisted of aquatic plants, algae, insects, fish, crustaceans and other aquatic animals (Shi et al., 2024). Among the terrestrial birds, Muscicapidae that includes old world flycatchers and accipitridae that included raptors werethe dominant families in the Godavari River. The dominance of these families have been highlighted from the Andhra Pradesh (Guptha et al., 2015), Maharashtra (Suryakant, 2017) and Telangana (Rajendra et al., 2021).

Upper zone of the Godavari River supported maximum richness of waterbirds. The high richness in upper zone might be due to low anthropogenic disturbance (see Chapter 10). In upper zone, specialist species like Northern Pintail (*Anas acuta*), River Tern (*Sterna aurantia*), Northern Shoveler (*Spatula clypeata*), Black-tailed Godwit (*Limosa limosa*) and Lesser-whistling Duck (*Dendrocygna javanica*) were present. The high abundance of Northern Pintail (*Anas acuta*) in upper zone might be due to low anthropogenic disturbance as Fredrickson (1991) has highlighted that Northern Pintail (*Anas acuta*) are very habitat specialist and are sensitive to disturbance. Borgmann (2011) also reported that human disturbance impacted the waterbirds. Bar-headed Goose (*Anser indicus*) was reported to be most abundant in the middle zone, species such as Eastern Cattle Egret (*Bubulcus coromandus*) and Indian-Pond Heron (*Ardeola grayii*) were found to be most abundant, although the Bar-headed Goose (*Anser indicus*), River Tern (*Sterna aurantia*) and Lesser-whistling Duck (*Dendrocygna javanica*) were also present in middle zone. In lower zone the Little Cormorant (*Microcarbo niger*), Great Cormorant (*Phalacrocorax carbo*) and Indian Cormorant (*Phalacrocorax fuscicollis*) were found large numbers. The cormorant population in the lower zone is highly abundant due to their social fishing behaviour, which involves forming a dense flock of predators to concentrate and take advantage of shared prey. This allows the cormorants to take advantage of areas with turbid waters (Paillisson at el., 2004).

Among the feeding guild the carnivore guild was dominant in waterbirds and water associate birds followed by insectivore, omnivore and herbivore in all three zones (upper, middle and lower). The domination of carnivore guild might be due to high abundance of fishes in the river. Ahmed et al. (2019) also reported the dominance of carnivore guild in waterbirds in Haripura-Baur Reservoir, western Terai-Arc landscape. The terrestrial birds were dominated by insectivore guild followed by granivore, omnivore, carnivore, frugivore and nectivore. Domination of insectivore guild have been observed in various terrestrial ecosystem of India ranging from Trans-Himalaya (Ahmed et al., 2014) to Terai-Arc Landscape (Ahmed et al., 2019).

The presence of endangered waterbirds like Black-bellied Tern (*Sterna acuticauda*) and Indian Skimmer (*Rynchops albicollis*) along with near-threatened species such as Grey-headed Fish-Eagle (*Haliaeetus leucoryphus*), Woolly-necked Stork (*Ciconia episcopus*), Painted Stork (*Mycteria leucocephala*), Black-tailed Godwit (*Limosa limosa*), Oriental Darter (*Anhinga melanogaster*), Black-headed Ibis (*Threskiornis melanocephalus*) and Alexandrine Parakeet (*Psittacula eupatria*) in the Godavari River emphasizes the vital need to protect these species outside the designated Protected Areas. Conserving their habitats outside these areas is important to ensure their survival and maintain healthy ecosystems. Notably, this investigation includes the entire Godavari River, providing a more detailed picture of avifaunal diversity than previous studies that concentrated and restricted to certain part of in Godavari River.

About 33% of the waterbirds and 25% had narrowly distributed in the Godavari River. Owing to the current anthropogenic pressure in the Godavari River, these species are highly susceptible to local extinction. A total of 973 km stretch including 524 km in the upper zone, 274 km in the middle, and 175 km in the lower zone of the Godavari River was found suitable for waterbirds and water dependent/associated species. This suggest that Godavari River still provide habitat for the waterbirds. These stretches should be provided with various degree of protection to conserve the waterbirds along Godavari River.

Of the total habitat suitable for the waterbirds, 678 km was suitable for 1 to 10 species of waterbirds. About 198 km falls under Wildlife Sanctuary viz., Jaikwadi WLS, Lanja Madugu Sivaram WLS, Pranahita WLS, Eturnagaram WLS and a national park viz., Papikonda NP. Yet 393 km is outside the PA and unprotected. If these are stretches brought under the purview of Wildlife (Protection) Act. 1972, it could facilitate and improve the conservation of birds in Godavari River. Table 8.10 provides the status of avifaunal studies in the Godavari and India.

Table 8.10 Status of avifaunal studies in the Godavari basin and India

Study area	Richness	Reference
Maharashtra, India,	667	Avibase, (2024)
Telangana	502	Avibase, (2024)
Overall in the Godavari River Basin	384	NRCD-WII, (2022)
Periyar Lake, Kerala, India	37 (WB)	David et al., (2022)
Narmada wetland area and its adjoining habitat of Mathwad Range Alirajpur Division, Madhya Pradesh, India	122	Rajput et al., (2021)
Mahanadi, Cuttack, Odisha, India	54 (WB)	Jyethi et al., (2021)
Overall, India	1364	Praveen et al., (2020)
Papikonda National Park, Andhra Pradesh (GRB)	63	Ray et al., (2020)
River Narmada Basin at Jabalpur District of Madhya Pradesh	172	Pant et al., (2020)
Narora Upper Stretch of Ganga River, India	140 Total (70 WB, 13 WAB, 57 TB	Vasudeva et al., (2020)
Majalgaon Reservoir and their tributaries, Marathwada region, Maharashtra (GRB)	84	Pawar et al., (2019)
Gosekhurd region of Godavari basin, Wainganga River India (GRB)	241	Patil et al., (2019)
Ganga River	86 (WB)	WII-NMCG, (2019)
Godavari River, Nanded District, Maharashtra (GRB)	42	Balkhande et al., (2017)
Godavari River Basin, Nanded District, Maharashtra (GRB)	168	Chavan et al., (2015)
East Godavari River estuarine ecosystem (EGREE), Andhra Pradesh (GRB)	264	Sathiyaselvam and Sreedhar, (2015)
Barak Valley, Assam, North East India	239	Dev, (2015)
Satapur Water Body, Renjal Mandal Dist. Nizamabad, Telangana (GRB)	69	Balkhande et al., (2014)
Kapla wetland of Barpeta district, Assam	30 (WB)	Das et al., (2014)
Barna Water Reservoir Narmada River Basim	64 (WB)	Balapure et al., (2013)
Tirunelveli and Tuticorin districts, Tamil Nadu, India	83 (WB)	Abhisheka et al., (2013)

(WB- Waterbird, WAB- Water Associated Bird, TB- Terrestrial Bird, GRB- Godavari River Basin)

References

Abhisheka K, David JP, Prashanth MB, Seshadri KS and Ganesh T (2013) First detailed survey of waterbirds in Tirunelveli and Tuticorin districts, Tamil Nadu, India. Journal of Threatened Taxa, 5(12), 4641-4652.

Ahmed T, Bargali HS, Bisht, D, Mehra, GS and Khan A (2019) Status of water birds in Haripura-Baur Reservoir, western Terai-Arc landscape, Uttarakhand, India. Journal of Threatened Taxa, 11(9), 14158-14165.

Ahmed T, Bargali HS and Khan A (2019) Status and distribution of avifauna in Ramnagar Forest Division, Western Terai-Arc Landscape, Uttarakhand. Indian Forester, 145(10), 935-945.

Ahmed T, Khan A and Chandan P (2014) Status of avifauna of Tsokar basin, Ladakh, Indian Trans-Himalaya. Biodiversity, environment and functional biology. Excellent Publishing House, New Delhi, 116-124.

Avibase (2024) The World Bird Databasehttps://avibase.bsc-eoc.org/checklist.jsp?region=INswmh (Accessed on 29-01-2024)

Balapure S, Dutta S and Vyas V (2013) Physico-chemical factors affecting the distribution of wetland birds of Barna Reservoir in Narmada Basin, Central India. International journal of biodiversity and conservation, 5(12), 817-825.

Balkhande JV, Waghmare BD and Shaik AI (2018) Census of birds on Godavari River in the month of January: A peak month of winter in Nanded (Maharashtra State).

Balkhande M, Vithalrao J, Jalander V and Sainath MG (2014) Check List of Birds from Satapur Water Body, Renjal Mandal Dist. Nizamabad, Telangana. Zoology, 3(5).

Bird Life International (2024) Important Bird Area factsheet: Narora. Downloaded from https://datazone.birdlife.org/site/factsheet/narora-iba-india on 27/03/2024

Bhattacharjee A and Bargali HS (2013) Diversity and abundance of wetland birds in Tumariya Wetland, Uttarakhand, India and management strategies for their conservation. Indian Forester 139(10): 899–905.

Borgmann KL (2011) A review of human disturbance impacts on waterbirds. Audubon California, 376, 1-23.

Buckton ST and Ormerod SJ (2002) Global patterns of diversity among the specialist birds of riverine landscapes. Freshwater Biology, 47(4), 695-709.

Chavan SP, Dudhmal D, Hambarde, S and Kulkarni AN (2012) Birds from Godavari River basin in Nanded district of Maharashtra state, India: annotated status and new reports. Methodology, 2015.

Das J, Pathak S, Kalita SN and Talukdar K (2014) Present status of aquatic avifaunal diversity in Kapla wetland of Barpeta district, Assam. Journal of Research in Biology, 4(6), 1451-1457.

David P, Sivakumar C and Manakadan R (2022) Status and abundance of waterbirds in Periyar lake, Kerala, india. Journal of the Bombay Natural History Society, 119(2), 125-133.

del-Hoyo J, Elliott A, Sargatal,J, Christie DA and de Juana E (2018) Handbook of the birds of the world.Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z. I., Knowler, D. J., Lévêque, C., Naiman, R. J., Prieur-Richard, A. H., Soto, D., Stiassny M. L. J., & Sullivan, C. A. (2006). Freshwater biodiversity: importance, threats, status and conservation challenges. Biological reviews, 81(2), 163-182.

Dev B (2015) Status of avifauna in Barak Valley, Assam, with special reference to Ardeidae family. IISRR International Journal of Research, 1(1), 89-95.

Dhakate PM, Patil TA and Bhartari R (2008) Wetland birds of Corbett Tiger Reserve Landscape, pp1974–1982. In: Sengupata, M. & R. Dalwani (eds.). Proceeding of Taal 2007: The 12th World Lake Conference, Jaipur, India.

Dudgeon D (2006) Freshwater biodiversity: importance, threats, status and conservation challenges. Biol. Rev. Camb. Philos. Soc. 81, 163-182.

Fredrickson LH and Heitmeyer ME (1991) 13.1. 3. Life History Strategies and Habitat Needs of the Northern Pintail.

Grimmett R, Inskipp C and Inskipp T (2019) Birds of the Indian Subcontinent: India, Pakistan, Sri Lanka, Nepal, Bhutan, Bangladesh, and the Maldives (2nd ed.). Bloomsbury Publishing.

Guptha MB, Kishore S, Prasad NS and Rao PC (2015) Birds of Seshachalam biosphere reserve, South-eastern Ghats of Andhra Pradesh, India. International Journal of Biodiversity and Conservation, 7(12), 435-452.

Jyethi A, Pradhan I, Barman, H and Kumar S (2021) Water birds of Mahanadi River areas of Cuttack, Odisha, India. Medico Biowealth of India.

Karl T, Melillo and Peterson T (2009) Global Climate Change Impacts in the United States (Cambridge: Cambridge University Press)

Kumar A, Sati JP and Tak PC (2003) Checklist of Indian waterbirds. Buceros, 8(1), 10-40. Checklist of Indian Waterbirds (bnhsenvis.nic.in)

Kumar P and SK Gupta (2009) Diversity and abundance of wetland birds around Kurukshetra, India. Our Nature 7: 212–217.

MacKinnon J and Phillipps K (1993) A Field Guide to The Birds of Borneo, Sumatra, Java, and Bali, The Greater Sunda Islands. Oxford: Oxford University Press.

Meybeck M (2003) Global analysis of river systems: from Earth system controls to Anthropocene syndromes. Philosophical Transactions of the Royal Society of London.

Series B: Biological Sciences, 358(1440), 1935-1955.

Meybeck M (2003) Global analysis of river systems: from Earth system controls to Anthropocene syndromes. Philos. Trans. R. Soc. B Biol. Sci. 358, 1935-1955.

Hengade N and Eldho TI (2019) Relative impact of recent climate and land cover changes in the Godavari river basin India. Journal of Earth System Science, 128 (2019), 10.1007/s12040-019-1135-4

NRCD– WII (2022) Godavari Riverscape: Ecological status and trends. Ganga Aqualife Conservation Monitoring Centre, Wildlife Institute of India, Dehra Dun. Uttarakhand, India. 141 pp.

Ormerod SJ and Tyler SJ (1993) Birds as indicators of changes in water quality. In Birds as monitors of environmental change (pp. 179-216). Dordrecht: Springer Netherlands.

Paillisson JM, Carpentier A, Le Gentil J and Marion L (2004) Space utilization by a cormorant (Phalacrocorax carbo L.) colony in a multi-wetland complex in relation to feeding strategies. Comptes Rendus Biologies, 327(5), 493-500.

Patil KG, Shende VA and Uke SB (2019) Bird habitats in Gosekhurd region of Godavari basin, across Wainganga River India. Journal of Biological Studies, 1(4), 146-159.

Pawar RT, Pathan TS and Bhosale YM (2019) Avifaunal study of Majalgaon Reservoir and their tributaries, District Beed, Marathwada region of Maharashtra, India. Int. J. Sci. Res. in Biological Sciences Vol, 6, 4.

Pant H, Malviya S and Dubey S (2020) Avian faunal diversity of river Narmada Basin at Jabalpur District of Madhya Pradesh. Journal of Natural Resource and Development, 15(2), 78-86

Praveen J and Jayapal R (2024) Checklist of the birds of India (v8.0). Website: http://www.indianbirds.in/india/ [Date of publication: 30 January 2024].

Ray P, Malla G and Manral U (2020) Avifaunal diversity along the riverine habitats of Papikonda National Park, Andhra Pradesh, India. Journal of Threatened Taxa, 12, 16993-16999.

Rajendra MP, Suharsha B and Deepika G (2021) Diversity and abundance of avifauna in forest research centre, Mulugu, Telangana, India. MOJ Eco Environ Sci. 2021;6(6):188–192.

Ray P, Malla G, Manral U, Johnson JA and Sivakumar K (2020) Avifaunal diversity along the riverine habitats of Papikonda National Park, Andhra Pradesh, India. Journal of Threatened Taxa, 12(14), 16993-16999.

Rajput A, Yadav SS and Kori PK (2021) Bird diversity of Narmada wetland area and its adjoining habitat of Mathwad Range, Alirajpur Division, Madhya Pradesh, India. International Journal of Applied Research, 7(8), 184-191.

Sathiyaselvam P and Sreedhar SS (2015) Status of water birds in East Godavari River estuarine ecosystem (EGREE), Andhra Pradesh. ENVIS Bulletin: Wildlife and Protected Areas 26: 284–293.

SoIB (2023) State of India's Birds factsheet. https://stateofindiasbirds.in/ Accessed on 2024-06-26.

Shi J, Meng L, Xia S, Liu S and Zhou L (2024) Habitat Suitability and Determinants for Anatidae in Multi-Watershed Composite Wetlands in Anhui, China. Animals, 14(7), 1010.

Suryakant PN (2017) Avifauna and Comparative Study of Threatened Birds at Urban Wetlands of Kolhapur, Maharashtra, India. International J. of Life Sciences, 5(4), 649-660.

Tak PC, Sati JP and Rizvi AN (2010) Status of waterbirds at Hathnikund Barrage wetland, Yamunanagar District, Haryana, India. Journal of Threatened Taxa 2(4): 841–844.

Vasudeva V, Garg JK, Badola R and Hussain SA (2020) Waterbird abundance and diversity along a stretch of Ganga River, India modified by construction of a barrage. bioRxiv, 2020-12.

Vörösmarty CJ, Léveque C, Revenga C, Bos R, Caudill C, Chilton J, Douglas EM, Meybeck M, Prager D, Balvanera P, Barker S, Maas M, Nilsson C, Oki T and Reidy CA (2005) Fresh water. Millennium ecosystem assessment, 1, 165-207.

Vörösmarty CJ, McIntyre PB, Gessner MO, Dudgeon D, Prusevich A, Green P, Glidden S, Bunn SE, Sullivan CA, Liermann CR and Davies PM (2010) Global threats to human water security and river biodiversity. nature, 467(7315), 555-561.

Wang X, Kuang F, Tan K and Ma Z (2018) Population trends, threats, and conservation recommendations for waterbirds in China. Avian Research, 9, 1-13.

Whelan CJ, Wenny DG and Marquis RJ (2008) Ecosystem services provided by birds. Annals of the New York academy of sciences, 1134(1), 25-60.

WII-NMGC (2019) Biodiversity Profile of the Ganga River: Planning aquatic species restoration of Ganga River, Wildlife Institute of India, Dehradun, Uttarakhand, India, pp-223.


09

MAMMALS

09

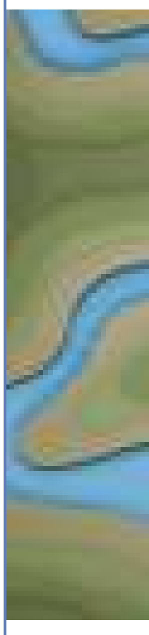
MAMMALS

Abstract

The Godavari River sustains a population of various species of conservation significance yet studies to assess the status and distribution of mammals inhabiting the riparian area of the Godavari River are lacking hitherto. We assessed the status and distribution of aquatic mammals to develop baseline information for their conservation in the Godavari River. A total of 14 species of mammals, including seven Schedule-I species, were recorded through direct and indirect sightings. All recorded species were terrestrial and belong to 6 orders and 11 families. Seven species, viz., Blackbuck (Antilope cervicapra), Common Palm Civet (Paradoxurus hermaphroditus), Golden Jackal (Canis aureus), Indian Crested Porcupine (Hystrix indica), Indian Grey Mongoose (Herpestes edwardsii), Ruddy Mongoose (Herpestes smithii) and Jungle Cat (Felis chaus) are listed as Schedule-I of the Wildlife (Protection) Amendment Act, 2022 were recorded in the Godavari River. A total of 785 km of stretch, that include 372 km in the upper zone, 247 km in the middle and 166 km in the lower zone of the Godavari River, was found suitable for mammals.

9.1 Introduction

The Godavari River encompasses diverse ecosystems, ranging from lush forests to fertile plains. The river supports a rich array of flora and fauna, making it a biodiversity hotspot (Sivakumar et al., 2016). The lush green cover along its banks provides a habitat for numerous plant and animal species, contributing to the overall ecological balance. Godavari River is rich habitat for flagship species like the Royal Bengal Tiger (*Panthera tigris*), with as many as six Tiger Reserves, viz., Indravati, Kanha, Pench, Melghat, Tadoba-Andhari and Kawal. Collectively, these Tiger Reserves are estimated to house a population of approximately 258 tigers (Nautiyal et al., 2023). Besides Tiger, the basin is home to a number of rare, endangered and threatened species like Leopard (*Panthera pardus*), Chausingha (*Tetracerus quadricornis*), Wild Water Buffalo (*Bubalus arnee*), Indian Python (*Python molurus*), Bengal Monitor (*Varanus bengalensis*), White-backed Vulture (*Gyps africanus*), Long-billed Vulture (*Gyps indicus*), Mugger Crocodile (*Crocodylus palustris*) and Smooth-coated Otter (*Lutrogale perspicillata*). The basin, also harbours a number of endemic animal species, like Bastar-Hill Mynah (*Gracula religiosa*) and Wild Water Buffalo (*Bubalus arnee*). Interestingly, the Godavari



River serves as a migration barrier for *Macaque spp*., restricting Rhesus Macaque (*Macaca mulatta*) to the north of Godavari and Bonnet Macaque (*Macaca radiata*) to south of Godavari. The Godavari mangroves are also home to another charismatic and threatened wetland-dependent species such as Smooth-coated Otter (*Lutrogale perspicillata*).

Yet studies to assess the status and distribution of mammals in the Godavari River are very rudimentary. Therefore, we conducted surveys to gather information on the status and distribution of these mammals to develop baseline information in the face of increasing anthropogenic pressure in the Godavari River. The present chapter highlights the status and distribution of terrestrial mammals and assesses habitat suitability of mammals in the Godavari River.

9.2 Methods of Assessment

A total of 41 transects were traversed with 5 km of sampling segments during the survey period focusing primarily on terrestrial mammals (Figure 9.1). However, direct and indirect evidence of aquatic mammal species was also recorded. All the indirect evidence of Otters (Spraints, kills, foot prints) was recorded along with river morphology (depth, width), river flow, bank characteristics such as bank substrate (rocky, muddy, gravel, pebbles), vegetation cover, anthropogenic data such as distance to human habitation, number of boats, fishing activity and water abstraction sites.

For various mammalian species, the encounter rate was evaluated using the formula:

$$\text{Encounter rate} = \frac{\text{No. of direct \& indirect evidence}}{\text{total length traversed (km)}}$$

Figure 9.1 Recording of Mammals in the Godavari River

Figure 9.2
Jungle cat (*Felis chaus*) – Tracks

9.3 Mammals of the Godavari River

A total of 14 species of mammals were recorded through direct and indirect sightings. All the recorded species were terrestrial. The recorded species belong to six orders and 11 families. Family Herpestidae, Sciuridae and Cercopithecidae were represented by two species each and Hystricidae, Viverridae, Leporidae, Suidae, Pteropodidae, Felidae, Bovidae and Canidae were represented by one species each (Figure 9.3). Significant species were omnivores (74%), herbivores (17%) and only 9% were carnivores in the region (Figure 9.4). Appendix 9.1 shows all the mammals recorded in this study.

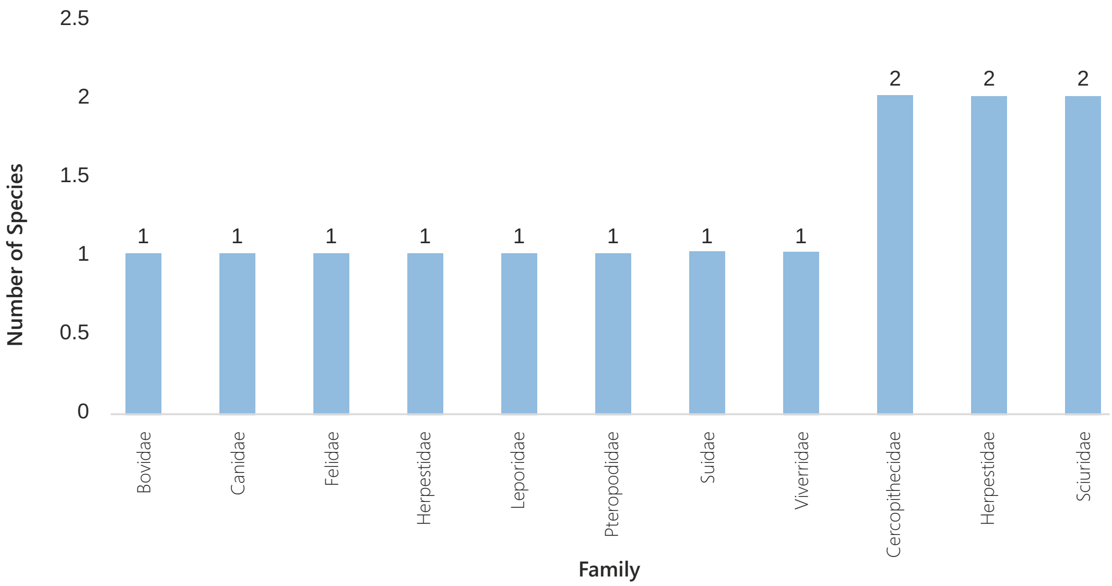


Figure 9.3
Number of mammal species recorded under different families in the Godavari River

Figure 9.4
Proportion of different mammalian groups in the Godavari River

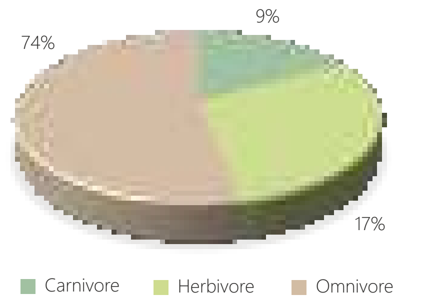
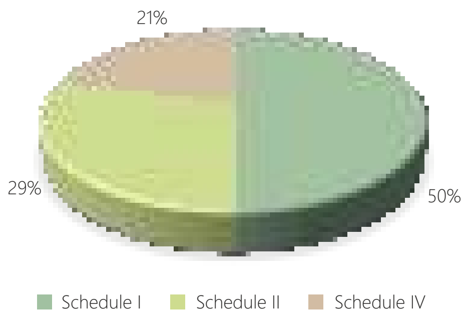


Figure 9.5
The proportion of mammals listed under various Schedule of the Wild Life (Protection) Amendment Act, 2022 in the Godavari River



9.3.1 Conservation status of mammals

Among the recorded species of mammals, viz., Indian Hare (*Lepus nigricollis*), Indian Grey Mongoose (*Urva edwardsii*), Northern Plains Gray Langur (*Semnopithecus entellus*), Blackbuck (*Antilope cervicapra*) and Rhesus Macaque (*Macaca mulatta*) are listed as Least Concern (LC) in the IUCN Red List (2024) of Threatened Species. In addition, Blackbuck (*Antilope cervicapra*), Common Palm Civet (*Paradoxurus hermaphroditus*), Golden Jackal (*Canis aureus*), Indian Crested Porcupine (*Hystrix indica*), Indian Grey Mongoose (*Herpestes edwardsii*), Ruddy Mongoose (*Herpestes smithii*) and Jungle Cat (*Felis chaus*) are listed as Schedule I of the Wild Life (Protection) Amendment Act, 2022. The rest of the other mammals comes under the Schedule II and IV categories. Table 9.1 and Figure 9.5 depict the conservation status of mammals in the Godavari River.

9.3.2 Status and distribution of mammals

The Godavari River exhibited relatively low mammal sightings, with an average of 2.93 evidence/km. Among the recorded species, the Jungle Cat (*Felis chaus*) had the lowest encounter rate, with only 0.01 evidence/km (Table 9.1).

The distribution of species varied across different river segments: the upper zone had 12 species, the middle zone had 9 species and the lower zone had 6 species. Segment 8 stood out with the highest species diversity (four species), while segments 3, 6, 12, 13, 15, 19, 27 and 28 each recorded three species. Conversely, segments 16, 21, 24 and 25 had the lowest species count, each hosting only one species (Figure 9.6 and Table 9.2)

Noteworthy mammals included the Ruddy Mongoose (*Herpestes smithii*) and Wild Boar (*Sus scrofa*) were observed in five segments, followed by the Golden Jackal (*Canis aureus*) and Common Palm Squirrel (*Funambulus palmarum*) recorded in four segments. The Blackbuck (*Antilope cervicapra*), Indian Crested Porcupine (*Hystrix indica*), Indian Hare (*Lepus nigricollies*) and Jungle Cat (*Felis chaus*) were each recorded in only one segment (Table 9.2).

Mammals	IWPA Status	IUCN	Sighting	Type of Evidence	Encounter Rate
Rhesus Monkey	Schedule IV	Least concern	Direct	Sighting	1.2
Northern Plains Gray Langur	Schedule II	Least concern	Direct	Sighting	0.48
Indian Hare	Schedule II	Least concern	Indirect	Pellets	0.33
Wild boar	Schedule II	Least concern	Indirect	Hoof	0.31
Common Palm Squirrel	Schedule IV	Least concern	Direct	Sighting	0.09
Five-striped Palm Squirrel	Schedule IV	Least concern	Direct	Sighting	0.08
Indian Crested Porcupine	Schedule I	Least concern	Indirect	Quills	0.08
Golden Jackal	Schedule I	Least concern	Direct	Sighting	0.07
Indian Grey Mongoose	Schedule I	Least concern	Direct	Sighting	0.07
Ruddy Mongoose	Schedule I	Least concern	Direct	Sighting	0.07
Blackbuck	Schedule I	Least concern	Direct	Sighting	0.05
Common Palm Civet	Schedule I	Least concern	Direct	Sighting	0.05
Indian Flying Fox	Schedule II	Least concern	Direct	Sighting	0.03
Jungle Cat	Schedule I	Least concern	Indirect	Scat	0.01
Total encountered rate					**2.93**

Table 9.1
Status of Mammals in the Godavari River

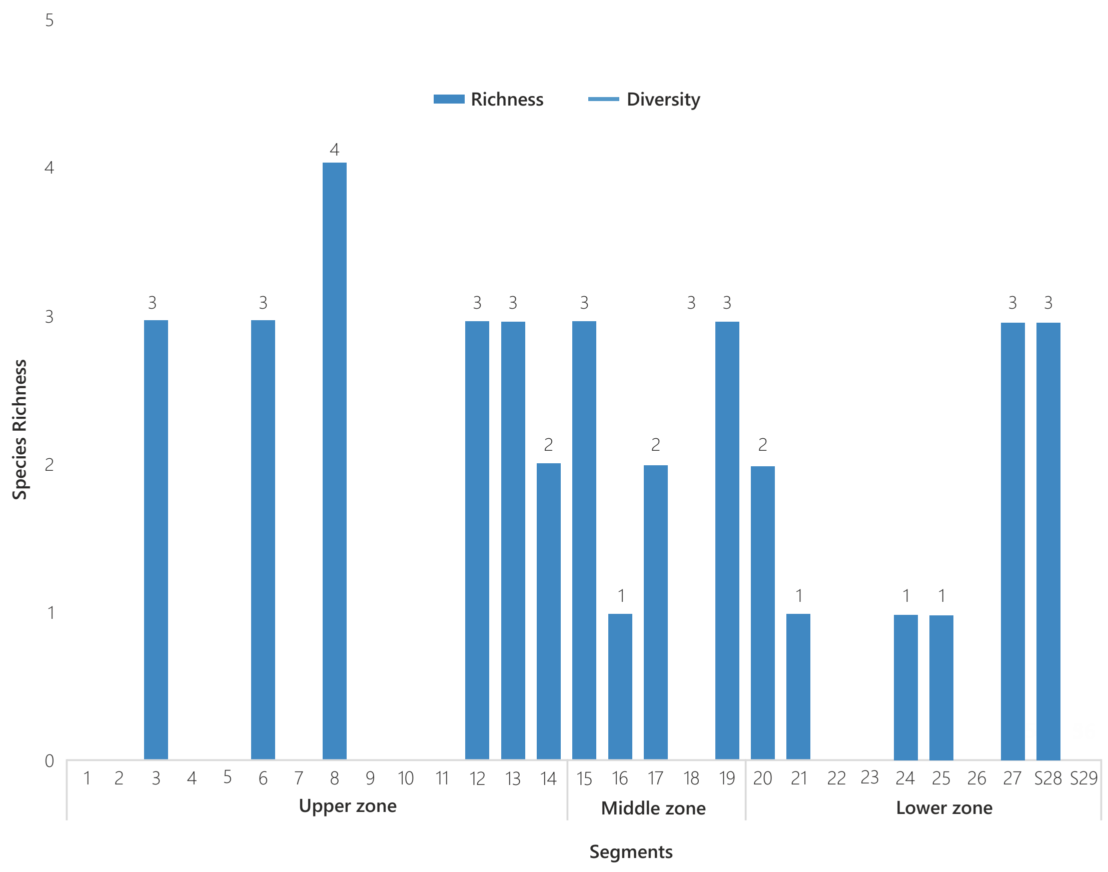


Figure 9.6
Zone-wise distribution of Mammals in the Godavari River, India

Table 9.2 Distribution of mammals in the Godavari River

Common Name	1	2	3	4	5	6	7	8	9	10
Blackbuck	-	-	-	-	-	-	-	-	-	-
Common Palm Civet	-	-	-	-	-	-	-	+	-	-
Common Palm Squirrel	-	-	+	-	-	-	-	-	-	-
Five-striped Palm Squirrel	-	-	-	-	-	+	-	-	-	-
Golden Jackal	-	-	-	-	-	-	-	-	-	-
Indian Crested Porcupine	-	-	+	-	-	-	-	-	-	-
Indian Flying Fox	-	-	-	-	-	-	-	-	-	-
Indian Grey Mongoose	-	-	-	-	-	-	-	+	-	-
Indian Hare	-	-	-	-	-	+	-	-	-	-
Jungle Cat	-	-	+	-	-	-	-	-	-	-
Northern Plains Gray Langur	-	-	-	-	-	-	-	-	-	-
Rhesus Macaque	-	-	-	-	-	-	-	-	-	-
Ruddy Mongoose	-	-	-	-	-	-	-	+	-	-
Wild boar	-	-	-	-	-	+	-	+	-	-

- Absent; + Present

9.4 Habitat suitability stretches of mammals

The Godavari River was assessed for its habitat suitability for mammals using the Maximum Entropy Model (MaxEnt; Phillips et al., 2006). A total of 785 km of stretch, including 372 km in the upper zone, 247 km in the middle zone and 166 km in the lower zone of the Godavari River was found suitable for mammals (Table 9.3 and Figure 9.7). In upper zone 32 km stretch was highly suitable, 40 km was moderately suitable and 300 km was less suitable for mammals. In the middle zone, 17 km stretch was highly suitable, 111 km was moderately suitable and 119 km was less suitable area. In the lower zone, 19 km of stretch was highly suitable, 100 km of stretch was moderately suitable and 47 km of stretch was less suitable for mammals. Figures 9.8 to 9.10 highlights the stretches of habitat suitability for mammals in different zones of the Godavari River.

Of the total stretches of habitat suitability of the Godavari River, 86 km falls under Wildlife Sanctuary and National Park, while the remaining is an unprotected area of the river (Table 9.4). All the suitable stretches of river fall in the states of Maharashtra, Telangana and Andhra Pradesh (Table 9.5).

Table 9.3 Suitable habitat stretches for Mammals in the Godavari River

River Zone	Zone length (km)	High Suitable (km)	Moderate Suitable (km)	Low Suitable (km)	Total Suitability (km)
Upper Zone	691	32	40	300	372
Middle Zone	318	17	111	119	247
Lower Zone	453	19	100	47	166
Total length	1462	68	251	466	785

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-
-	-	+	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	-
-	-	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-
-	-	-	+	-	+	-	-	-	+	-	-	-	-	+	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	+	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	-	-	+	-
-	+	-	-	-	-	+	-	-	-	+	-	-	-	-	-	+	-	-
-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	+	-

Table 9.4 Suitable habitat stretches for Mammals under Protected Areas

Protected Area	Habitat suitable stretches of Godavari River under Protected Area (km)	Godavari River stretches under Protected Area (km)
Jaikwadi WLS	3	74
Lanja Madugu Sivaram WLS	16	17
Pranahita WLS	3	3
Eturnagaram WLS	7	58
Papikonda NP	41	46
Total length	**70**	**198**

Table 9.5: Hotspot locations of high suitable stretches for Mammals in the Godavari River

River zone	High suitable stretches (km)	GPS Location Start Location	End Location	Location	District	State
Upper Zone	3.4	19.899 N / 74.4159 E	19.870 N / 74.438 E	Dharangaon to Umri Canal	Ahilyanagar	Maharashtra
	8	19.38193 N / 75.56776 E	19.3813 N / 75.63585E	Bhagwan Nagar (Bid) to Sawase wasti (Jalna)	Beed-Jalna	
	12.3	19.0974 N / 77.16238 E	19.1243 N / 77.23685 E	Kawalgaon Wadi to Pimpalgaon	Nanded	
Middle Zone	8	18.9864 N / 78.4245 E	18.9758 N / 78.4853 E	Kodicherla to Domchanda	Nizamabad	Telangana
	9	19.07179 N / 78.84661 E	19.0406 N / 78.9185 E	Rampur to Gondserial	Nirmal	
Lower Zone	3.9	18.80875 N / 79.9491 E	18.7899 N / 79.9770 E	Janampalli to Rajannapalii	Gadchiroli	
	5.6	17.64582 N / 80.90083E	17.64366 N / 80.95198 E	Purushottapatnam to Thupakulagudem	East Godavari	Andhra Pradesh
	1.5	17.44857 N / 81.53241 E	17.4395 N/ 81.5486 E	Peddagudem to Ganugolagondi	East Godavari	
	1.5	17.0515 N / 81.7421 E	17.0631 N / 81.7486 E	Torredu	East Godavari	

Riverine habitat in the middle zone of the Godavari River

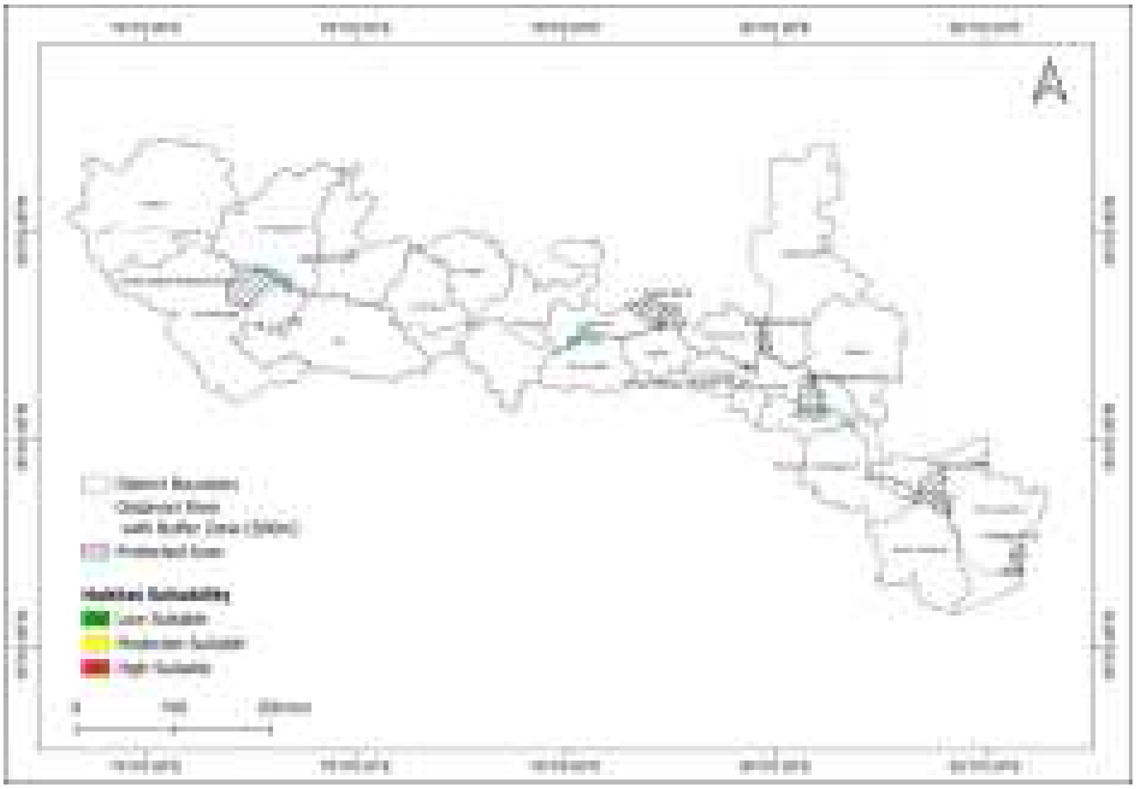


Figure 9.7 Habitat suitability stretches of mammals in the Godavari River

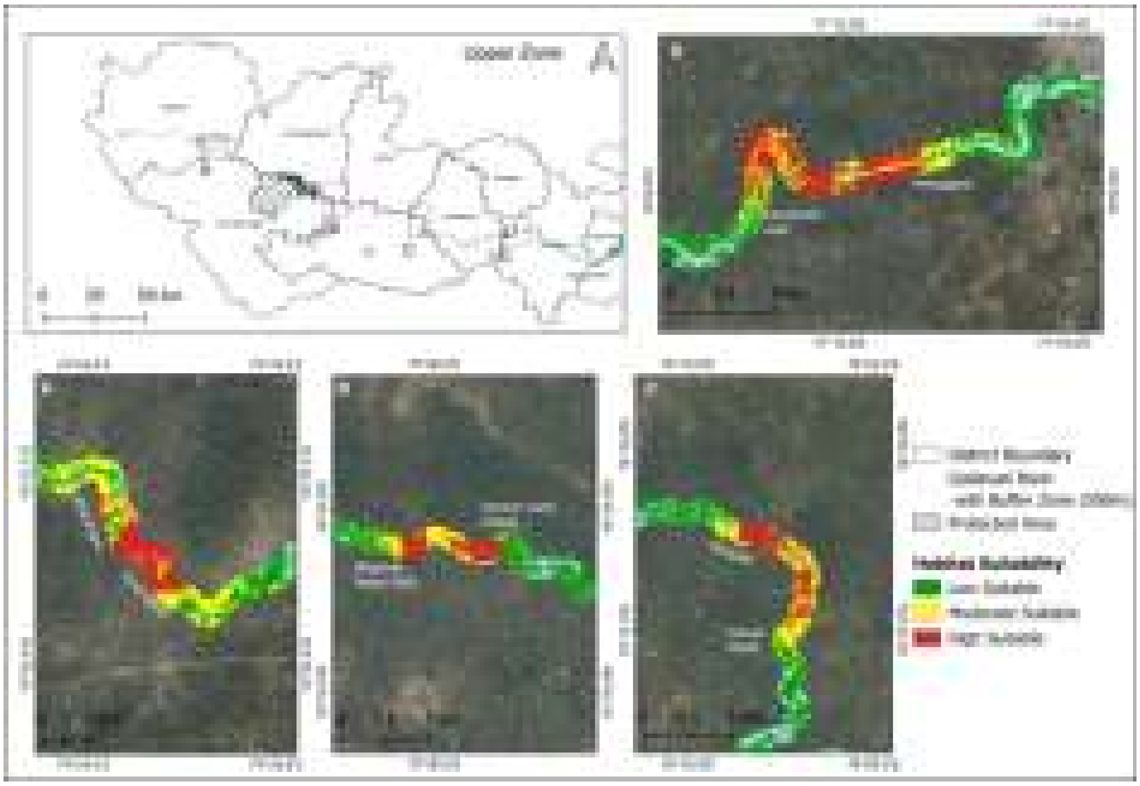


Figure 9.8 High suitable habitat stretches of mammals in the upper zone of the Godavari River

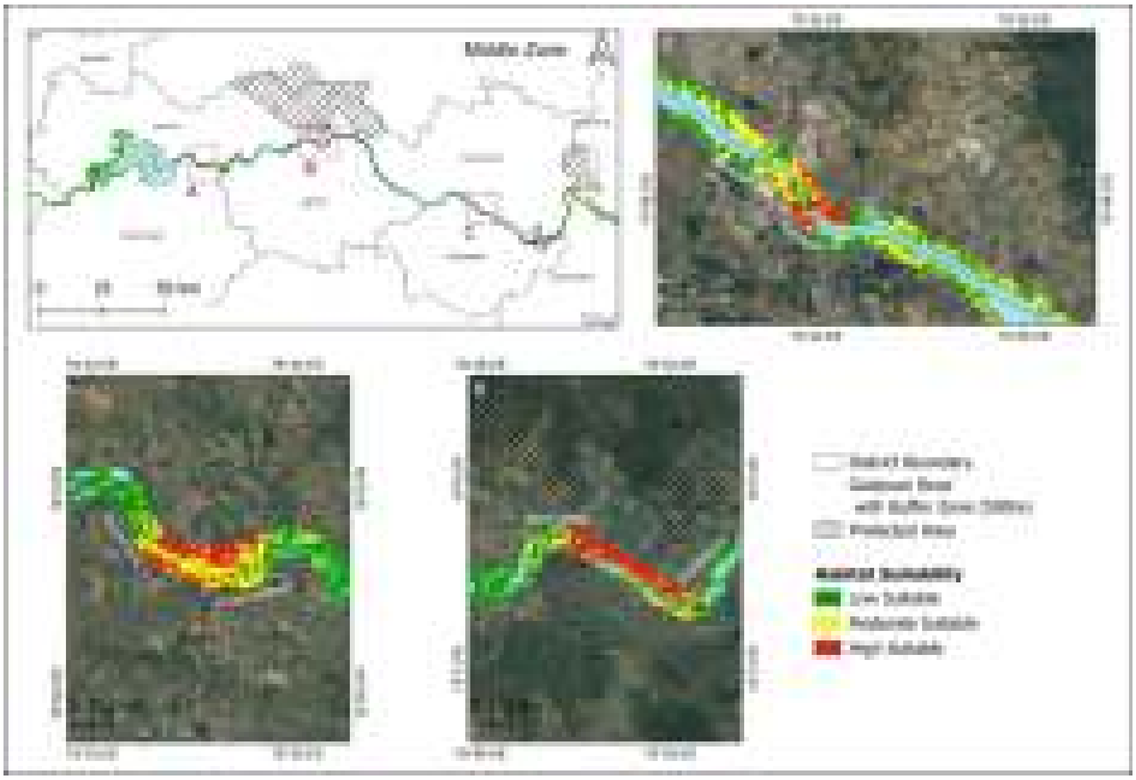


Figure 9.9
High suitable habitat stretches of mammals in middle zone of the Godavari River

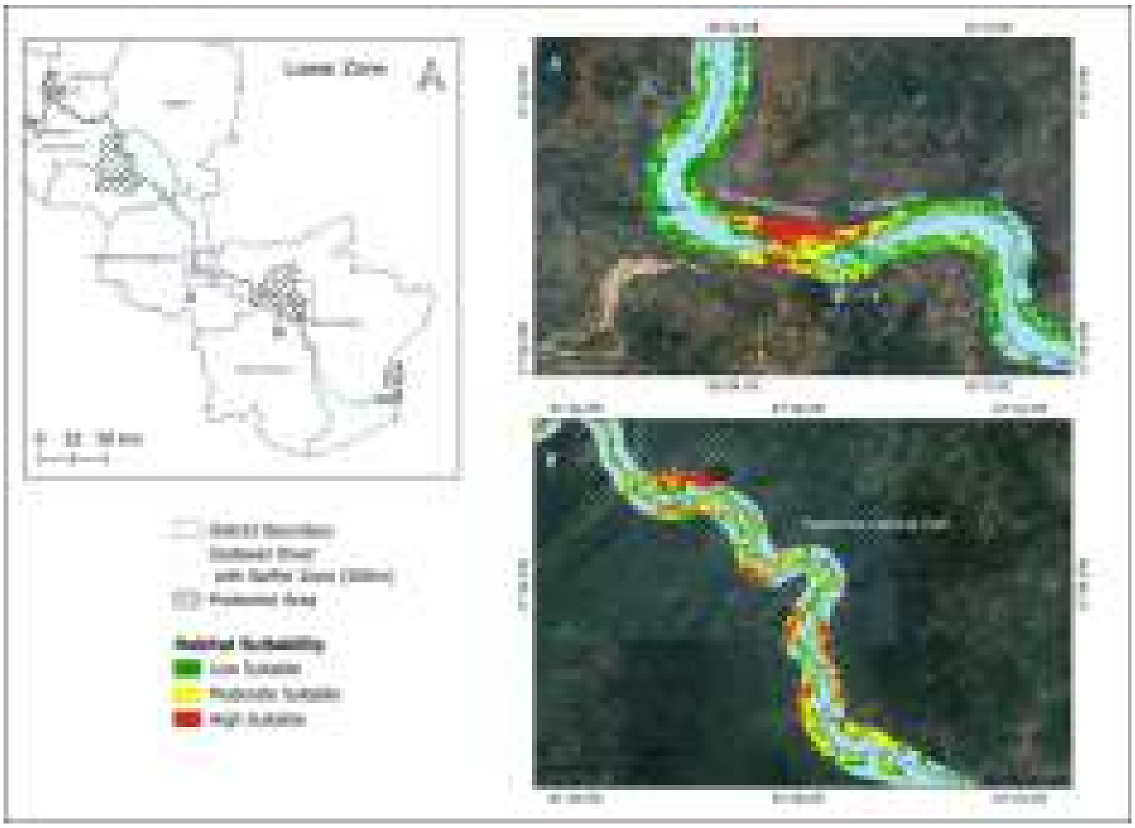


Figure 9.10
High suitable stretches of mammals in the Lower zone of the Godavari River

9.5 Discussion

A total of 14 species of mammals, all terrestrial species (encounter rate of 2.93), were recorded in the riparian area of the Godavari River. Our study found that the mammal diversity represents 50% of the total mammalian fauna documented across the entire Godavari River. (NRCD-WII, 2022). The richness recorded in our study was similar to the findings of Banarjee et al. (2010) and Sivakumar et al. (2016). Our results revealed that the Godavari River supported seven Schedule-I species (Blackbuck (*Antilope cervicapra*), Common Palm Civet (*Paradoxurus hermaphroditus*), Golden Jackal (*Canis aureus*), Indian Crested Porcupine (*Hystrix indica*), Indian Grey Mongoose (*Herpestes edwardsii*), Ruddy Mongoose (*Herpestes smithii*) and Jungle Cat (*Felis chaus*)) and four Schedule II species (Indian Flying Fox (*Pteropus medius*), Indian Hare (*Lepus nigricollis*), Northern Plains Gray Langur (*Semnopithecus entellus*) and Wild Boar (*Sus scrofa*)) of the Wild Life (Protection) Amendment Act, 2022. This indicates that the Godavari River supports many conservation efforts for significant mammalian fauna, which have been documented in various Protected Areas within the Godavari River (Srinivasulu and Nagulu, 2002; Sivakumar K et. al., 2016; Aditya and Ganesh, 2017: Shankar et al., 2020). Primates, viz., Rhesus Macaque (*Macaca mulatta*) and Northern Plains Gray Langur (*Semnopithecus entellus*), were the most encountered mammals in the Godavari River while Jungle cat (*Felis chaus*) the least encountered mammalian species. Rhesus Macaque (*Macaca mulatta*) and Northern Plains Gray Langur (*Semnopithecus entellus*) can tolerate human disturbance (Ahmed et al., 2019). Their abundance is high in the Godavari River could be related to their tolerance of high human disturbance. However, the presence of mustelid species was not recorded in our survey. This could be due to anthropogenic disturbances, viz., water abstraction particularly along Godavari River stretches in the state of Maharashtra. Therefore, there is an urgent need for the adoption of policies and actions for the conservation of the Godavari River. Table 9.6 summarises the studies on mammals in the Godavari River.

A total of 785 km of stretch including 372 km in the upper zone, 247 km in the middle zone and 166 km in the lower zone of the Godavari River was found suitable for mammals. Of the total stretches of habitat suitable for mammals along the Godavari River, 86 km falls under the Wildlife Sanctuary and National Park, while the remaining area is an unprotected. The identified conservation priority stretches should be brought under the purview of the Wildlife (Protection) Amendment Act, 2022., which could facilitate the conservation of mammals in the Godavari River.

Table 9.6 Status of Mammals of the Godavari River, India

Study area	Species richness	Threatened	Endemic	Reference
Overall, Godavari River	28	11	-	NRCD WII, (2022)
Nallamala Hills, Andhra Pradesh	74	4	1	Srinivasulu and Nagulu, (2002)
East Godavari River Estuarine Ecosystem				
Andhra Pradesh	14	2	-	Sivakumar et al., (2017)
East Godavari mangrove delta Andhra Pradesh	6	2	-	Shankar et al., (2020)
Papikonda National Park, East and West Godavari district, Andhra Pradesh	55	8	-	Aditya and Ganesh, (2017)
Etunagaram WLS, Warangal dist (Andhra Pradesh), Telangana.	14	3		Banarjee et al., (2010)

References

Aditya V and Ganesh T (2017) Mammals of Papikonda Hills, northern Eastern Ghats, India. Journal of Threatened Taxa, 9(10), 10823–10830.

Ahmed T, Bargali HS, Verma N and Khan A (2019) Mammals outside protected areas: status and response to anthropogenic disturbance in the Western Terai-Arc Landscape. Zoological Society, 74(2), 163-170.

Benarjee G, Srikanth K, Ramu G and Ramulu KN (2010) Ethnozoological study in a tropical wildlife sanctuary of Eturunagaram in the Warangal district, Andhra Pradesh, India. Journal of Traditional Knowledge, 9(4), 701–704.

IUCN (2024) The IUCN Red List of Threatened Species. Version 2023-1.

Nautiyal JP, Lone AM, Ghosh T, Malick A, Yadav SP, Ramesh C and Ramesh K (2023). An Illustrative profile of Tiger Reserves of India. EIACP Programme. Centre (MoEFCC), Wildlife Institute of India, Chandrabani, Dehradun-248001 Uttarakhand, India. pp-314.

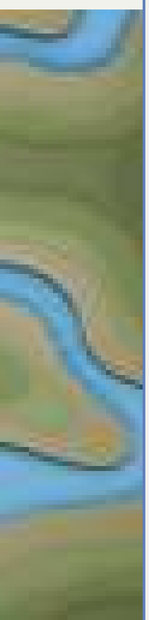
NRCD-WII (2022) Godavari Riverscape Ecological Status and Trends. Ganga Aqualife Conservation Monitoring Centre, Wildlife Institute of India, Dehradun, Uttarakhand, India. pp.141

Shankar A, Salaria N, Sanil R, Chackaravarthy SD and Shameer TT (2020) Spatio-temporal association of fishing cats with the mammalian assemblages in the East Godavari mangrove delta, India. Mammal Study, 45(4), 303-313.

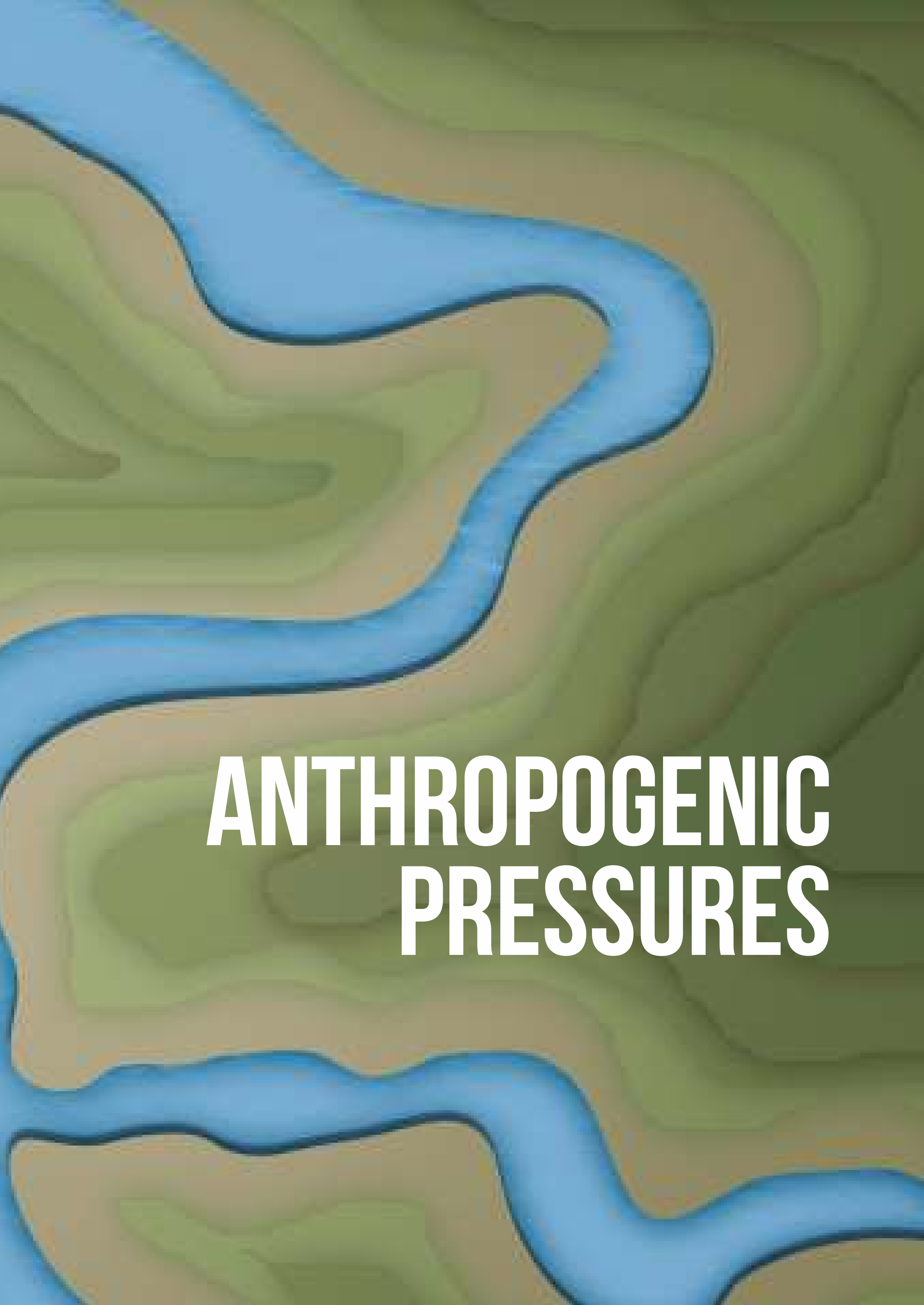
Sivakumar K, JA Johnson, Gopi GV, Panna Lal, Rajashekar PV, Bhadury P, Kumar R , Kathula T, Tulsi R, Malla G, Ray P, Bagaria P, Anand D and Prasad L (2016) Establishment of Knowledge Management System for East Godavari River Estuarine Ecosystem, Andhra Pradesh. Technical Report, Wildlife Institute of India, Dehradun. 406 pp.

Srinivasulu C and Nagulu V (2002) Mammalian and avian diversity of the Nallamala Hills, Andhra Pradesh. Zoos' Print Journal, 17(1), 675-684.

Steven JP, Robert PA and Robert ES (2006) Maximum entropy modeling of species geographic distributions. Ecological Modeling. 190 (3-4), 231-259.



10



ANTHROPOGENIC PRESSURES

10

ANTHROPOGENIC PRESSURES

Abstract

We assessed the quantum and distribution of various anthropogenic pressures along with heavy metal pollution in the Godavari River. Godavari River is threatened by 13 different types of anthropogenic activities viz., Grazing (55.24%), water abstraction (17.45%), fishing (11.70%), waste dumping (4.34%), sand mining (3.25%), ferry (2.55%) free-ranging dogs (2.12%), bathing ghats (1.37%), religious ghats (0.71%), developmental activities (0.66%), cremation (0.38%), aquatic vegetation extraction (0.14%) and brick kiln (0.09%). Observed parameters such as pH, Conductivity, Salinity, Nitrate and TDS were higher than the recommended limits of USEPA Aquatic Life Quality Criteria. Among the heavy metals the concentrations of zinc, mercury, lead, and cadmium in water exceeded the permissible levels as well, the concentration of Chromium in sediment was found to be higher than the permissible limits. Additionally, EDCs such as PAEs OCPs , OPs, Pyrethroid, Pharmaceuticals, BPA, Hormones, HPCP were detected in both water and sediment. The bioaccumulation profile showed high accumulation of PAEs, followed by Zn, BPA, OCPs, and Cr, indicating their persistence and potential risks to human health through consumption of contaminated aquatic organisms.

10.1 Introduction

The Godavari is the largest of the east-flowing rivers in peninsular India. The river flows for approximately 1465 kilometers and has a catchment area of approximately 312,812 square kilometers (NCIWRD, 1999). Its basin encompasses nearly 9.5% of the country's total geographical area. Originating from Trimbakeshwar in the Western Ghats within the Nashik district of Maharashtra, the river gracefully traverses the expanse from the Western to the Eastern Ghats, cutting across the Deccan Plateau. The Godavari River meander's through the states of Maharashtra, Chhattisgarh, Telangana, and Andhra Pradesh before culminating its journey in the Bay of Bengal.

During its entire course, the Godavari River is subjected to various anthropogenic pressures such as dams, pollution from domestic and industrial sources, the introduction of non-native species, sand mining, overexploitation of fishing resources, and water abstraction for irrigation purposes (NRCD-WII, 2022). Population growth has also exacerbated the dependency on the Godavari River water. The water demand for Nashik, Marathwada, and Vidharbha regions for urban areas is 290.45 mm^3, 350 mm^3 and 1109.80 mm^3 respectively (https://wrd.maharashtra.gov.in/Site/Upload/PDF/Godawari-Khand2.pdf). As population

continue to grow and agriculture becomes more intensive, water demand is likely to increase. Construction of 921 dams, 28 barrages, 18 weirs, one anicut, 62 lifts, and 16 powerhouses in the Godavari basin impacts the river's natural flow and morphology, resulting in habitat fragmentation for aquatic wildlife (Dudgeon, 2011; Lakra et al., 2011; Khedkar et al., 2014). Additionally, the construction of these structures disrupts natural sediment transport, leading to erosion and sedimentation issues in the river basin. Fish fauna has been exploited from the Godavari River system since time immemorial. Over-exploitation of the fish poses a significant anthropogenic pressure on the aquatic ecosystem, leading to ecological imbalances, depletion of fish stocks, and negative impacts on biodiversity. The industrial and sewage effluents released from industrialized areas and urbanized areas along the course of River Godavari viz., Nashik, Ahilyanagar, Aurangabad, Jalna, and Karimnagar districts have deterioration of the water quality. Previous studies have highlighted the higher concentrations of trace and toxic elements such as Fe and Zn in the Godavari River (Hussain et al., 2017). All these anthropogenic pressures cumulatively impact the river ecosystem and its biodiversity.

Even then studies to assess the anthropogenic pressure in the Godavari River are restricted to the assessment of pollution levels that too in certain stretches of the Godavari River. Here we assessed the quantum of anthropogenic pressure, water quality, and heavy metal pollution in the Godavari River for biodiversity conservation.

10.2 Methods of Assessment

10.2.1 Anthropogenic pressure

To gather data on anthropogenic pressures in the Godavari River, within each 5 km sampling segment three transects were established. Each transect was traversed and various anthropogenic activities such as fishing, ferry boats, grazing, sand mining, waste dumping, bathing ghats/ dhobi ghats, encroachments, water extraction, and industrial outlets were counted. To assess the disturbance score of each sampling site, we used a Likert scale measurement for every anthropogenic pressure and ranked them on a 5-point scale from 0 to 4 based on the frequency of their sighting. 0 was encounter regarded as no disturbance, 1 as low, 2 as moderate, 3 as high, and 4 as very high disturbances. Only mining was ranked as high disturbance (4). These scores were added to find out the disturbance index of each segment. The disturbance score for each anthropogenic pressure is highlighted in Table 10.1.

Table 10.1 Values for Likert scale measurement

Anthropogenic Pressure	Score	Scale	Disturbances
Fishing	0	0	No Disturbances
	1	1-10	Low Disturbance
	2	11-20	Moderately Disturbances
	3	21-50	Highly Disturbances
	4	51-100	Very High Disturbances
Sand mining	0	0	No Disturbances
	1	1-3	Low Disturbance
	2	4-6	Moderately Disturbances
	3	7-10	Highly Disturbances
	4	11-15	Very High Disturbances
Cattle grazing	0	0	No Disturbances
	1	1-100	Low Disturbance
	2	101 -200	Moderately Disturbances
	3	201-500	Highly Disturbances
	4	501 - 1000	Very High Disturbances
Water abstraction	0	0	No Disturbances
	1	1-10	Low Disturbance
	2	11-20	Moderately Disturbances
	3	21-31	Highly Disturbances
	4	41-50	Very High Disturbances
Cremation	0	0	No Disturbances
	1	1	Low Disturbance
	2	2	Moderately Disturbances
	3	3	Highly Disturbances
	<5	4	Very High Disturbances
Encroachments	0	0	No Disturbances
	1	1	Low Disturbance
	2	2	Moderately Disturbances
	3	3	Highly Disturbances
	<5	4	Very High Disturbances
Ferry area	0	0	No Disturbances
	1-4	1	Low Disturbance
	5-6	2	Moderately Disturbances
	6-10	3	Highly Disturbances
	11-25	4	Very High Disturbances
Religious ghats	0	0	No Disturbances
	1	1	Low Disturbance
	2	2	Moderately Disturbances
	3	3	Highly Disturbances
	<10	4	Very High Disturbances
Dumping waste	0	0	No Disturbances
	1-5	1	Low Disturbance
	6-10	2	Moderately Disturbances
	11-15	3	Highly Disturbances
	16-20	4	Very High Disturbances
Bathing ghats	0	0	No Disturbances
	1	1	Low Disturbance
	2	2	Moderately Disturbances
	3	3	Highly Disturbances
	<10	4	Very High Disturbances

Anthropogenic Pressure	Score	Scale	Disturbances
Free-ranging dogs	0 1 2 3 <10	0 1 2 3 4	No Disturbances Low Disturbance Moderately Disturbances Highly Disturbances Very High Disturbances
Brick kiln	0 1 2 3 4	0 1 2 3 4	No Disturbances Low Disturbance Moderately Disturbances Highly Disturbances Very High Disturbances
Aquatic vegetation extraction	0 1 2 3 4	0 1 2 3 4	No Disturbances Low Disturbance Moderately Disturbances Highly Disturbances Very High Disturbances

10.2.2 Assessment of River Pollution

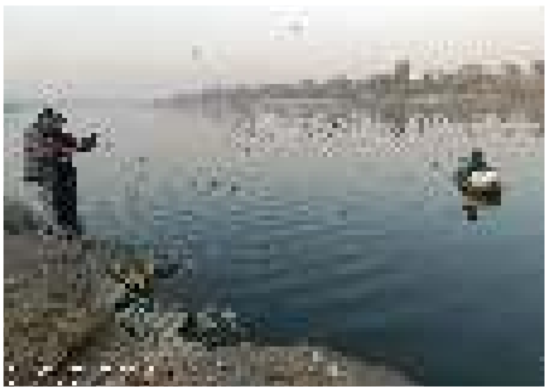
At each sampling site, Physico-chemical parameters of water viz., pH, Electrical Conductivity, Total Dissolved Solid (TDS), Salinity, Dissolved Oxygen (DO), and Nitrate levels were evaluated using a YSI Pro-DSS Multi-parameter probe.

To analyse the heavy metals in the Godavari River, both water and sediment samples were collected. For the water samples, 50 ml of water was taken from the middle of the river in a falcon tube, and about 1.5 ml of nitric acid (HNO_3) was added to the sample to lower the pH to below 2. For the sediment samples, 0.5 to 1 kg was collected from the riverbank at a depth of 5 cm using an auger. Both water and sediment samples were stored in an ice box at approximately 2°C to preserve their condition and were then transported to the Wildlife Institute of India, where they were kept at 4°C. Furthermore, the water and sediment samples were treated with strong acids to break down the matrix and release the heavy metals into a solution. The digested samples were analysed using an ICP-MS instrument to detect the elements.

To analyse the Endocrine Disruptive Compounds (EDCs) in the Godavari River, both water and sediment samples were collected. For the water samples, 1000 ml was collected from the middle of the river in an amber bottle with 1.5 ml of Methanol added for primary preservation. For the sediment, 0.5 to 1 kg was collected from the riverbank at a depth of 5 cm using an auger. Both water and sediment samples were stored in an ice box at approximately 2°C to preserve their condition and were then transported to the Wildlife Institute of India, where they were kept at 4°C. EDCs levels in the water were analysed using a Solid Phase Extraction method, followed by LC-MS/GC-MS. Similar to the water analysis, the EDCs levels in the sediment were measured through Ultrasonication/Sonolysis, employing LC-MS/GC-MS. This method ensures precise detection of EDCs in both water and sediment samples.

To examine the extent of bioaccumulation of heavy metals and EDCs, nine fish species (*Systomus sarana, Ompok bimaculatus, Oreochromis niloticus, Channa striata, Labeo calbasu, Labeo fimbriatus, Osteobrama cotio, Wallago attu,* and *Cirrhinus mrigala*) were collected from Godavari River. Samples were preserved in ice and transported to the lab. Biological samples were processed for heavy metals and EDCs following the methodology of Sah et al. (2023) and QuEChERS, respectively.

Figure 10.1 Data collection and analysis of water samples of Godavari River



10.3 Anthropogenic pressures

The Godavari River is subjected to various types and degrees of anthropogenic disturbances. Thirteen types of disturbances were identified, namely, aquatic vegetation extraction, fishing, cattle grazing, sand mining, brick-kiln, free-ranging dogs, waste dumping (domestic/religious activities), religious ghats, bathing ghats, ferry areas (ferry ghat/ boat), developmental activities, cremation and water abstraction. The anthropogenic site encountered the most by Cattle grazing (55.24%), water abstraction (17.45%), and fishing (11.70%). It was followed by the waste dumping (4.34%), sand mining (3.25%), ferry boats (2.55%), free-ranging dogs (2.12%), bathing ghats (1.37%), religious ghats (0.71%), developmental activities (0.66%), cremation (0.38%), aquatic vegetation extraction (0.14%) and brick-kiln (0.09%) respectively. In the upper zone, water abstraction (50%) was identified as the highest disturbing anthropogenic activity in the Godavari River, followed by grazing (10.39%) and fishing (10.11%). In the middle zone, fishing (40.51%) was the highest disturbance, followed by water abstraction (33.58%). In the lower zone of the Godavari River, grazing (74.77%) was the highest disturbances, followed by fishing (6.78%). Figure 10.2 highlights the frequency of various anthropogenic disturbance encountered in the Godavari River.

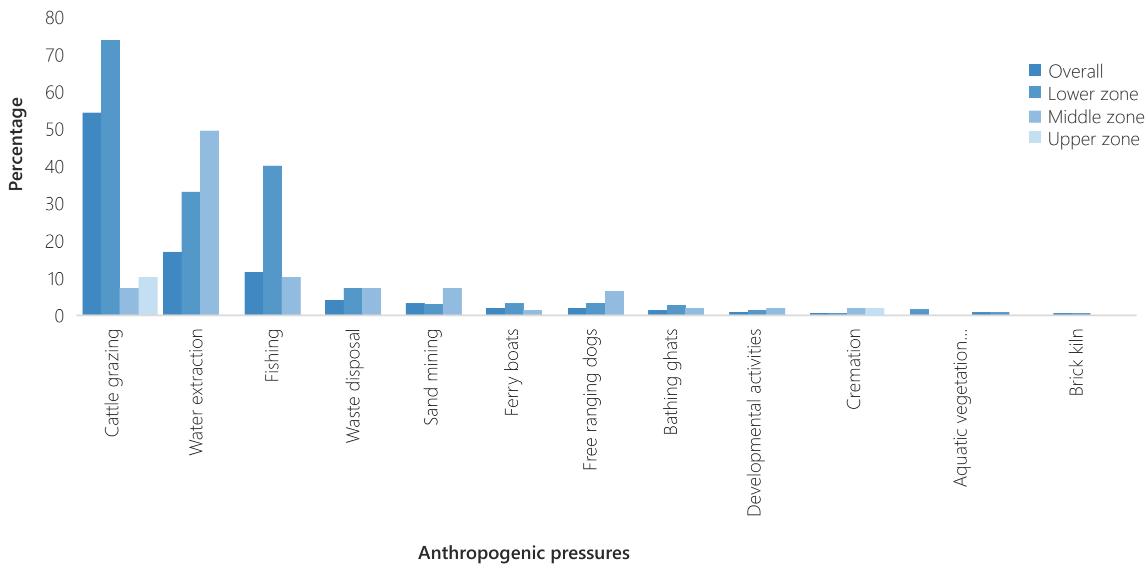


Figure 10.2 Relative composition of the anthropogenic activities recorded in the Godavari River.

Table 10.2 List of anthropogenic disturbances assessed in the diferent zones of Godavari River

Upper Zone	Middle Zone	Lower Zone
Fishing	Fishing	Fishing
Grazing	Grazing	Grazing
Sand mining	-	Sand mining
Dumping of waste	Waste dumping	Waste dumping
Water abstraction	Water abstraction	Water abstraction
Free-ranging dogs	Free-ranging dogs	Free-ranging dogs
Brick-kiln	Brick-kiln	-
Religious ghats	Religious ghats	Religious ghats
Bathing ghats	Bathing ghats	Bathing ghats
Ferry area	-	Ferry area
Developmental activities	Developmental activities	Developmental activities
Cremation grounds	Cremation grounds	-
-	-	Aquatic vegetation extraction

10.4 Anthropogenic activities at various sampling segments

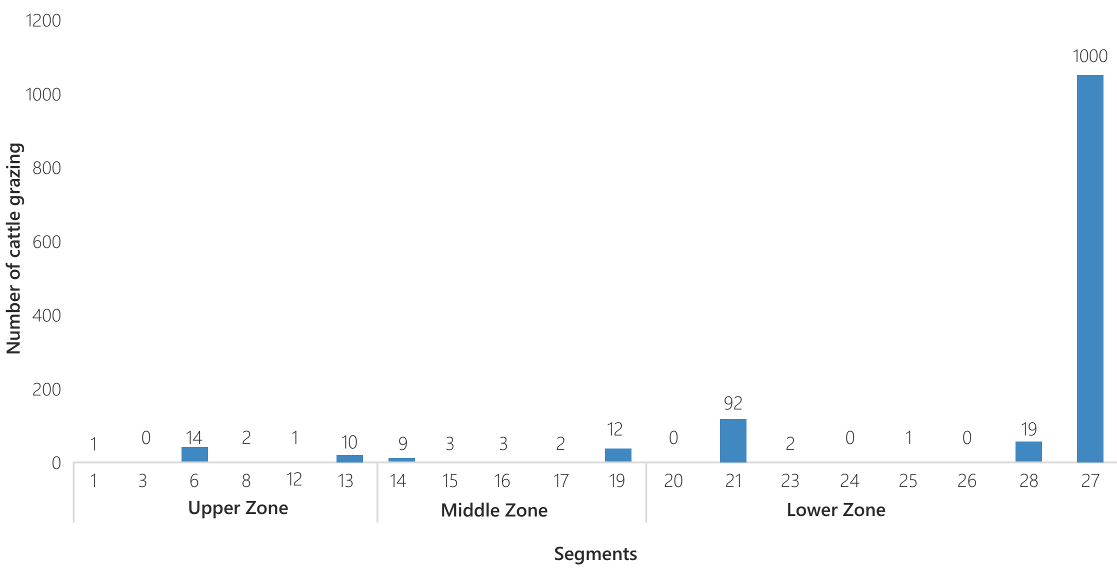
The anthropogenic disturbances encountered at all the sampling segments, were highest in the upper zone (12 types) in comparison with the lower zone (11 types) and middle zone (10). Activity-wise disturbances in all segments of the river are detailed below:

10.4.1 Grazing

Grazing was maximum in the lower zone and followed by in the upper zone and middle zone (Figure 10.4). While this is depicting only the site were grazing is occurring. Grazing was maximum in segment 27, followed by segment 21. Segment 27 was located inside the Papikonda National Park, Raju District (Figure 10.3), and segment 21 was located around Neelampalle, Warangal District. Segments 3, 20, 24, and 26 were devoid of grazing pressure. Figure 10.3 explaining the whole scenario of grazing.

Figure 10.3 Livestock grazing observed in the Godavari River

Figure 10.4 Grazing of livestock observed in different zone and segments of the Godavari River



10.4.2 Water abstraction

Water abstraction was observed maximum in the upper zone and it was followed by the lower zone and middle zone (Figure 10.6). High water abstraction was observed in Segment 6 (Gulaj Dam, Aurangabad District) and followed by Segment 12 (Rahati, Parbhani District), and Segment 23 (Ramanakkapeta, Mulugu District). Segments 21 and 27 located in the lower zone were devoid of water abstraction. Figure 10.5 highlights the water abstraction in the Godavari River.

Figure 10.5 Water extraction observed in the Godavari River

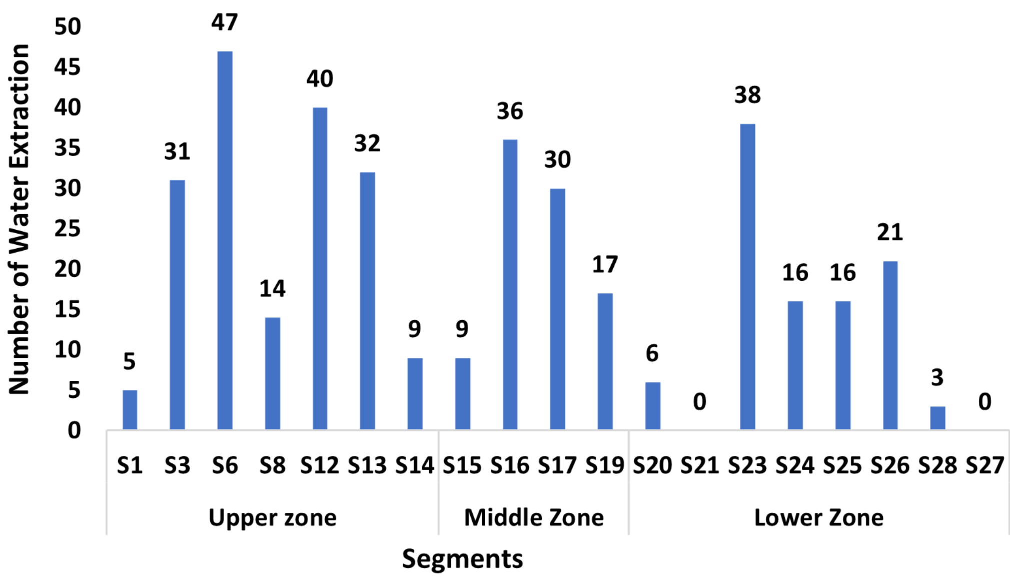


Figure 10.6 Water extraction observed in different zones and segments of Godavari River

10.4.3 Fishing

Fishing pressure was highest in the middle zone, and followed by lower zone (Figure 10.8). The upper zone had the least fishing pressure. Fishing events in the sampling segment ranged between 4 to 67. Fishing pressure was maximum in segment 15, located in Aloor, Nizamabad District. It was followed by segment 19 (Indaram, Adilabad District), and segment 28 (around Gandi Pochamma Ammavari Temple, Rajahmundry District). Figure 10.7 highlights the quantum of fishing recorded in various sampling segments.

Figure 10.7 Fishing activities encountered in the lower zone of the Godavari River

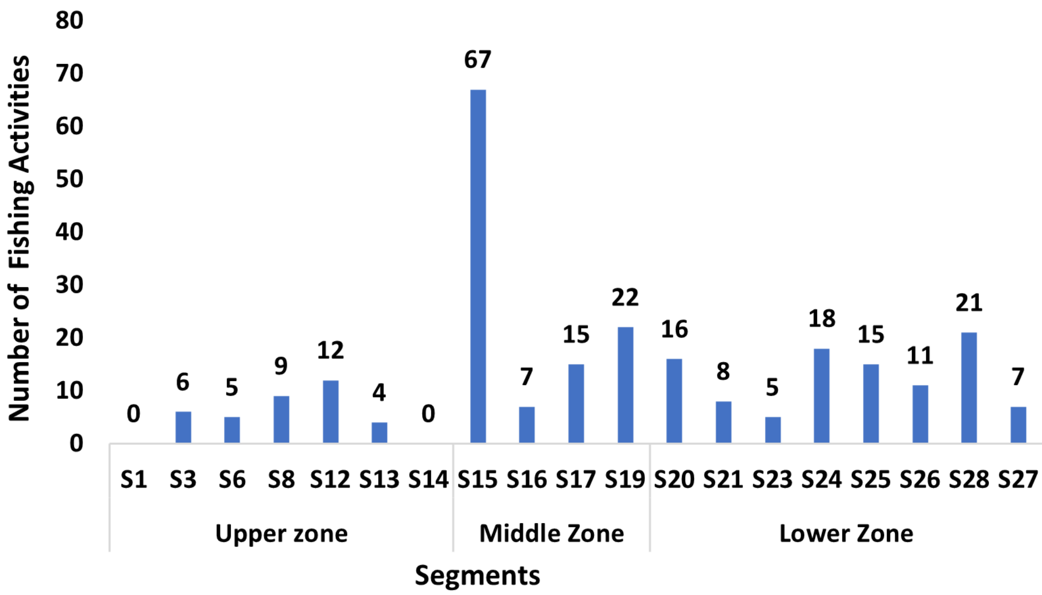


Figure 10.8 Fishing activities encountered in different zones and segments of Godavari River

10.4.4 Waste dumping (domestic/religious)

Waste dumping sites were observed in all sampling segments of the Godavari River (Figure 10.10). However, the extent of these disturbances varied across different sampling segments and between the upper and middle zones. Waste dumps in the Godavari River were maximum in the lower zone, followed by the upper zone and middle zone. The number of waste dumps however was consistent in all sampling segment,. Maximum number of waste dumps was recorded in the sampling segment 20 located around Manddikunta, Karimnagar District. Figure 10.9 highlights the waste disposal activities along the Godavari River.

Figure 10.9
Waste disposal activities encountered the Godavari River

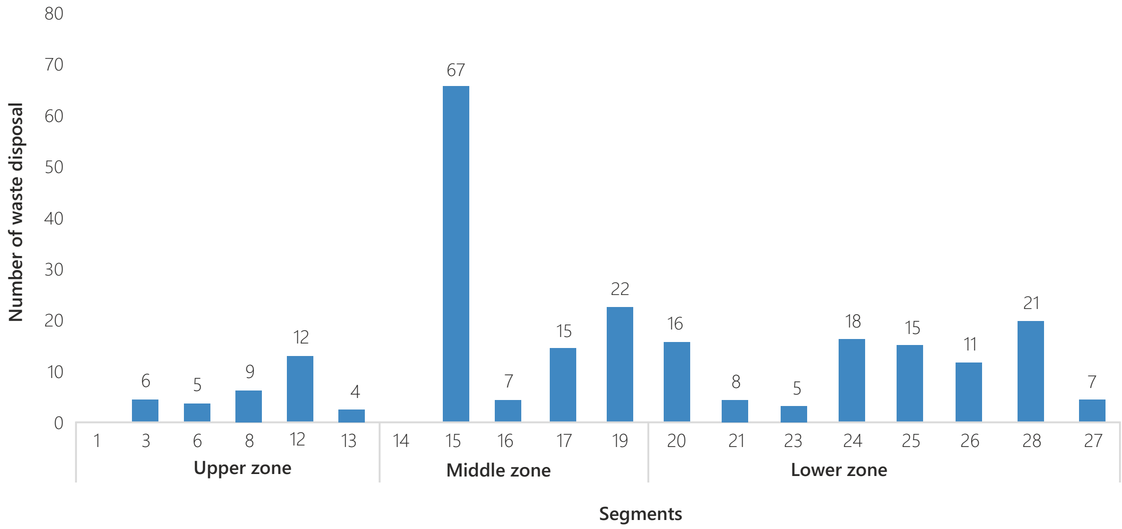


Figure 10.10
Waste disposal pressure encountered in different zones and segments of the Godavari River

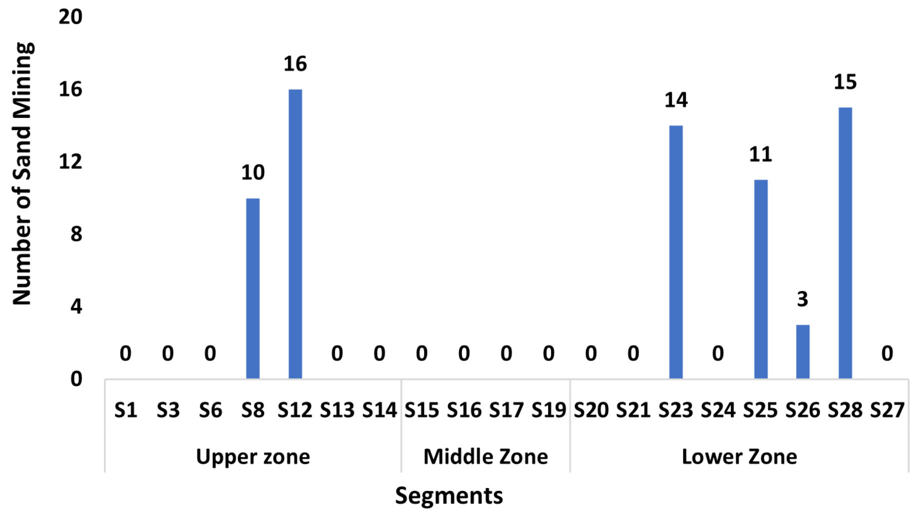
10.4.5 Sand mining

Sand mining was pronounced in the lower zone (Figure 10.12). However mining was not present in every sampling segment but was limited to segments 23, 25, 26, and 28 in the lower zone, 8 & 12 segments of the upper zone.

Sand mining was maximum in the sampling segment 12 (Rahati, Parbhani District) followed by segment 28 (Gandi Pochamma Ammavari Temple, Rajahmundry District) and segment 23 (Ramanakkapeta, Mulugu District). Figure 10.11 highlights the sand mining activities along the Godavari River.

Figure 10.11
Mining of sand near Kaleshwaram along the Godavari River

Table 10.12
Sand mining activities encountered in different zones and segments of the Godavari River

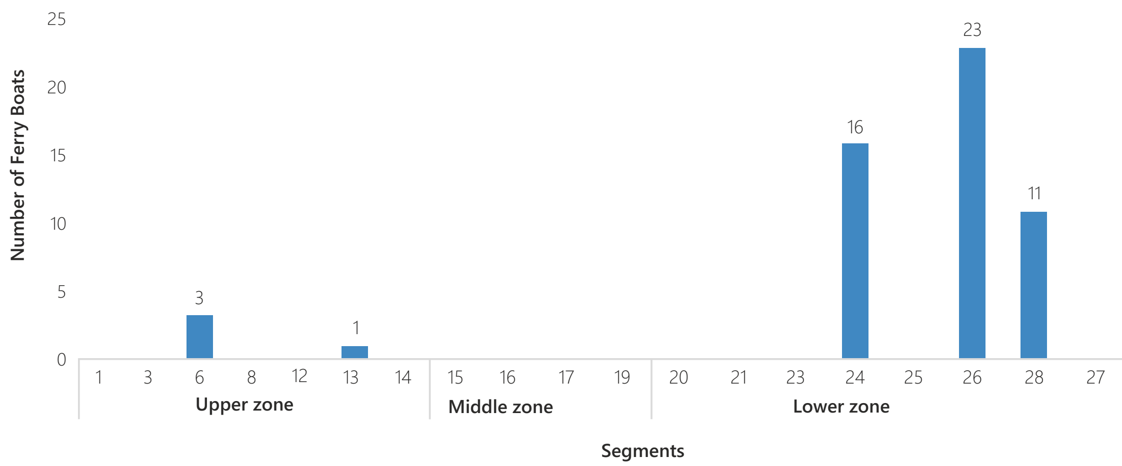


10.4.6 Ferry boats

The Godavari River experienced no significant anthropogenic disturbance as a result of ferry boat operations. In the upper zone, ferry boats were operational in sampling segments 6 and 13. The highest frequency of ferry boats was recorded in sampling segment 26 (Chinnapolipaka, Khammam District), followed by segments 24 (Chinnaravigundem, Mulugu District) (Figure 10.14) and 28 (around Gandi Pochamma Ammavari Temple, Rajahmundry District) of the lower zone. Figure 10.13 highlights the ferry boat activities along the Godavari River.

Figure 10.13
Ferry boats along the Godavari River

Figure 10.14
Ferry boats encountered in different zones and segments of the Godavari River



10.4.7 Free-ranging dogs

The upper zone had maximum free-ranging dogs, followed by the lower zone and middle zone. Sighting of free-ranging dogs was maximum in sampling segment 14 followed by segment 12 (in the upper zone) and segment 24 (lower zone). Segment 14 was located along Kondalwadi, Nanded District, segment 12 along Rahati, Parbhani District, and Segment 24 along Chinnaravigundem, Mulugu District. Sampling segments 8, 21, 23, and 28 were free of free-ranging dogs. Figure 10.15 highlights free-ranging dogs encountered along the Godavari River.

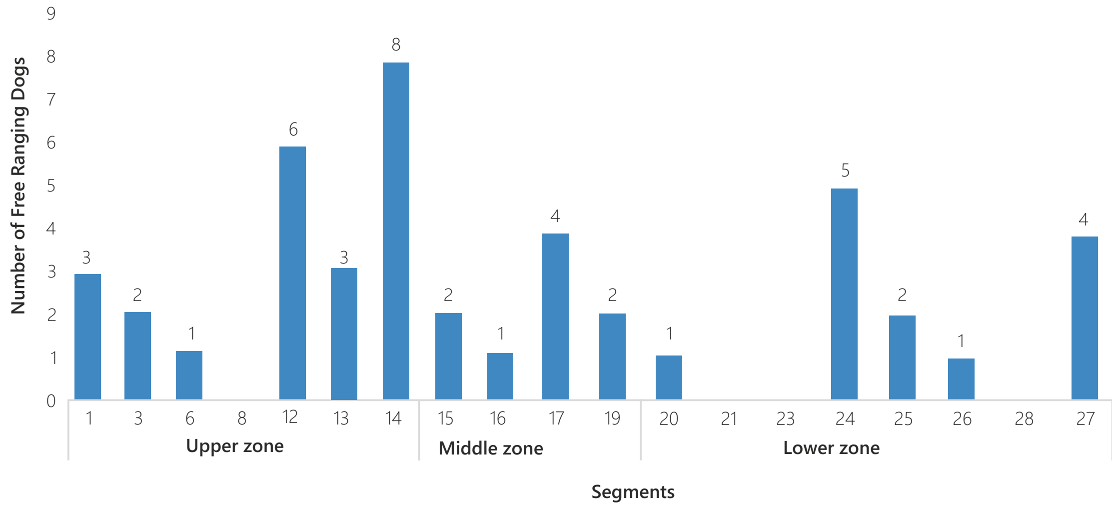


Figure 10.15 Number of free-ranging dogs encountered in different zones and segments of the Godavari River

10.4.8 Bathing ghats

Bathing ghats were frequently encountered in the lower zone and it was followed by the middle and upper zone (Figure 10.17). Segment 17 (Gudchiriyal, Nirmal District) in the middle zone, and segments 23 (Ramanakkapeta, Mulugu District), 26 (Chinnapolipaka, Khammam District), and 28 (Gandi Pochamma Ammavari Temple, Rajahmundry District) in the lower zone had the maximum number of bathing ghats. Sampling segments 13, 14, and 25 were devoid of bathing ghats. The frequency of these activities was consistent in all sampling segments. Figure 10.16 highlights the bathing ghats found along the Godavari River.

Figure 10.16 Bathing ghat along the Godavari River

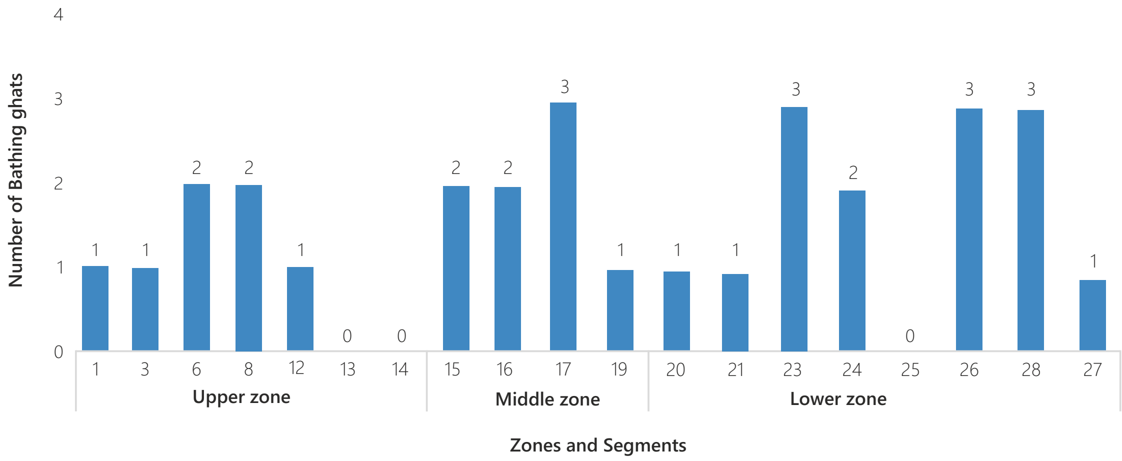


Figure 10.17 Bathing ghats encountered in different zones and segments of the Godavari River

10.4.9 Religious ghats

Activities in the religious ghats are commonly observed in most locations where temples are located next to rivers (Figure 10.18). In the current study, the upper zone had the maximum number of religious ghats, and followed by lower and middle zones. Segment 6 located downstream of the Gulaj Dam in Aurangabad District had the maximum number of religious ghats. Figure 10.19 highlights religious ghats encountered in the various segments of the Godavari River.

Figure 10.18 Religious ghats along the Godavari River

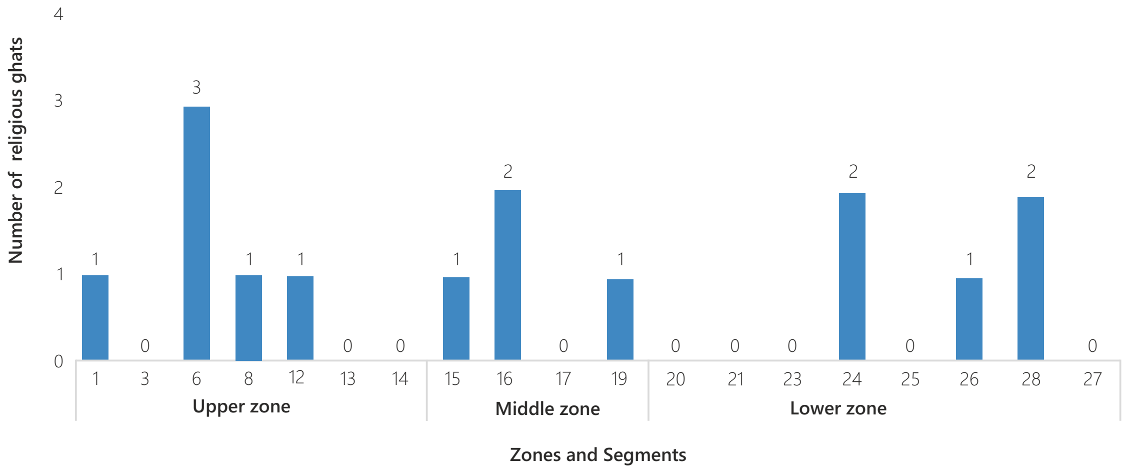


Figure 10.19 Religious ghats encountered in different zones and segments of the Godavari River

10.4.10 Developmental structures

The developmental activity includes the construction of dams, barrages, bridges, etc, along the riverside or nearby rivers (Figure 10.20). Developmental structure on the river, was maximum in the upper zone, followed by middle and lower zone. Sampling segment 19 (Indaram, Adilabad District – middle zone) had the maximum developmental structure and followed by segments 8 and 12 (upper zone). Figure 10.21 highlights the developmental structure along the Godavari River.

Figure 10.20
Dam along the Godavari River

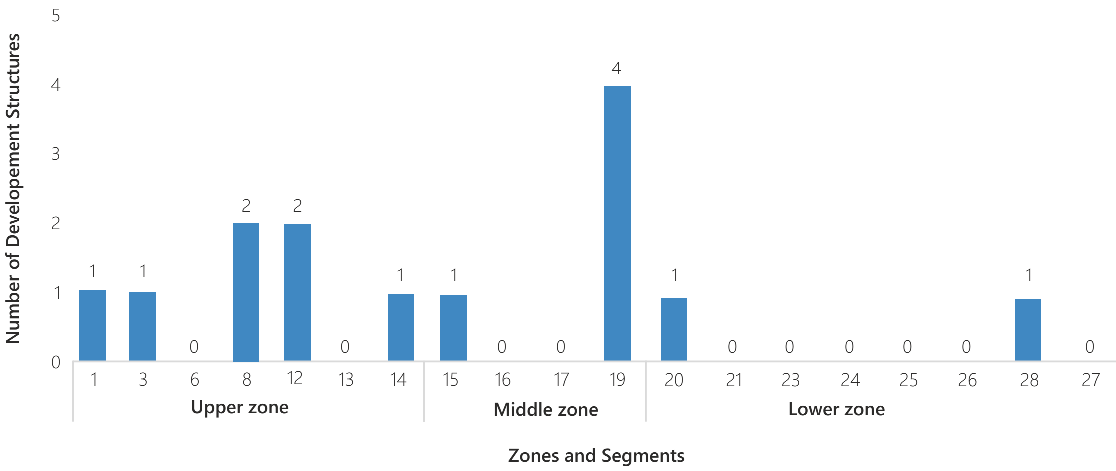


Figure 10.21
Development structures observed in different zones and segments of the Godavari River

10.4.11 Crematoriums

Crematorium sites were observed in the upper and middle zones. The lower zone was devoid of the crematorium sites. Segment 12 located along the Rahati villages in Parbhani district and segment 19 along the Indaram village in Adilabad district supported two crematorium sites each. Figure 10.22 highlights the number of cremation sites along the Godavari River.

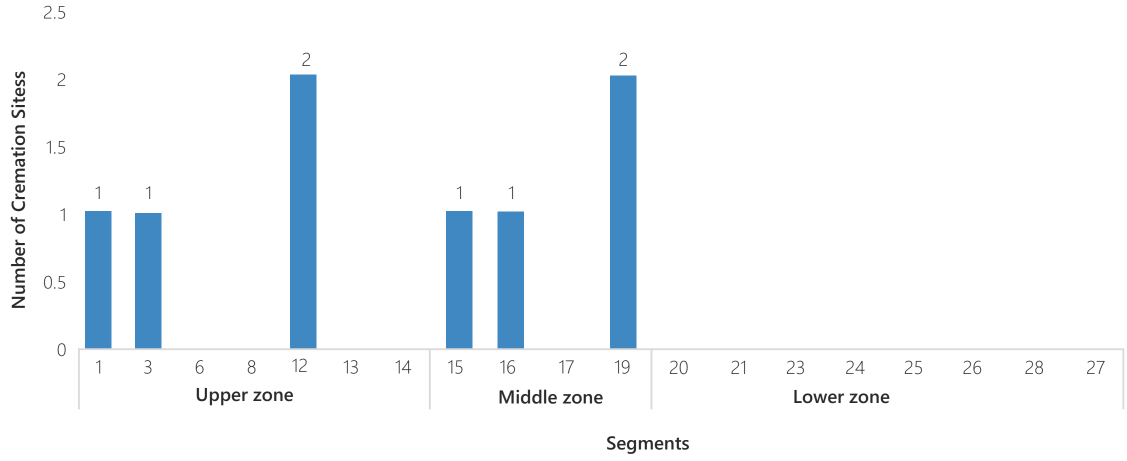


Figure 10.22 Cremation sites encountered in different zones and segments of the Godavari River

10.4.12 Brick kiln

Very few establishment of bricks kiln was observed along the course of the Godavari River. One was observed in sampling segment 6 in the upper zone and sampling segment 19 in the middle zone. Figure 10.23 highlights the sighting of brick kiln sites along the Godavari River.

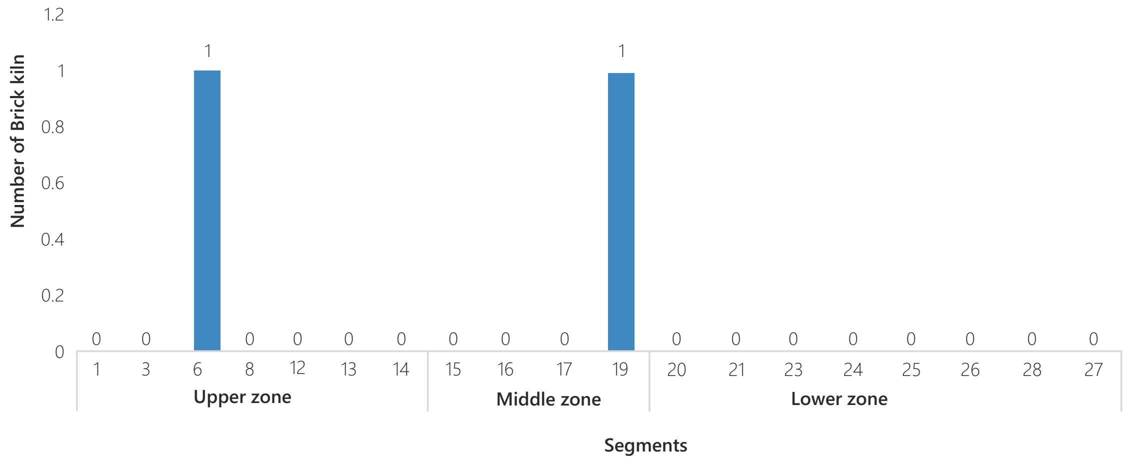


Figure 10.23 Brick kiln sites encountered along the Godavari River

10.4.13 Aquatic vegetation extraction

Extraction of the aquatic vegetation was observed in the lower zone only. It was recorded in the sampling segments 24 and 28. Figure 10.24 highlights the recording of aquatic vegetation extraction

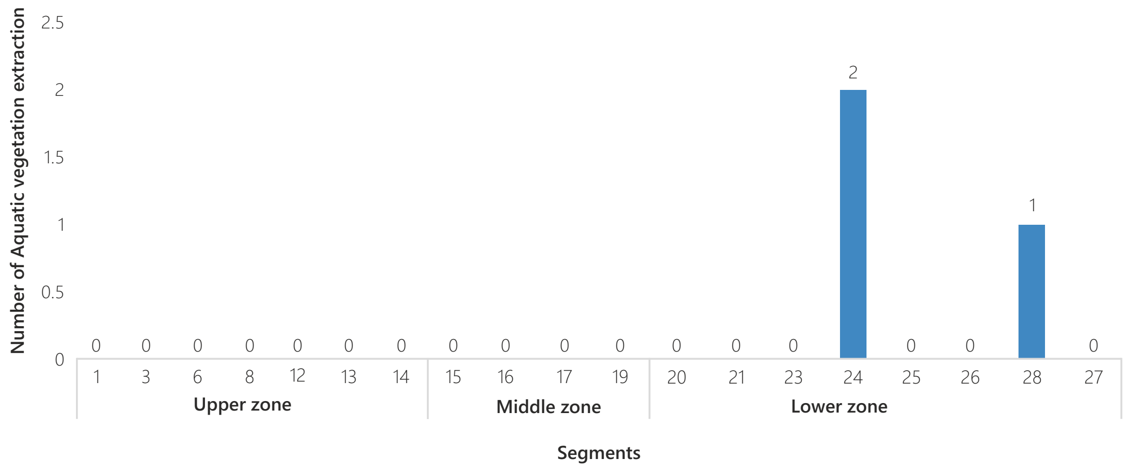


Figure 10.24 Aquatic vegetation extraction activity in different zones and segments of the Godavari River

10.5 Anthropogenic disturbance index

The Godavari River experiences a range of anthropogenic disturbances of different types and magnitudes. This study identified thirteen distinct disturbance categories: Aquatic vegetation extraction, fishing, cattle wading/ grazing, sand mining, brick kiln, free-ranging dogs, waste dumping (domestic/religious activities), religious ghats, bathing ghats, ferry areas (ferry ghat/ boat), developmental activities, cremation, and water abstraction. Most of the sampling sites had four or more disturbance types indicating that the Godavari River is highly disturbed. Remarkably, sampling segments 12, 19, and 28 were the highly disturbed segments as seven out of the 13 disturbance types were present at these sites. Additionally, sampling segments 6, 15, 24, and 26 contained six types of disturbances, signifying the level of disturbance to the river ecosystem. (Figure 10.25).

The analysis of disturbance scores revealed that segment 13 had the highest disturbance score in the Godavari River, having a total score of 36.4. It was followed by segment 16 with a disturbance score of 30.8, and segment 3 scored 30. In contrast, segment 28 exhibited the lowest level of any disturbances, scoring 4.8. Segments 21 and 27 had an anthropogenic score of zero, as they remained entirely free from anthropogenic disturbances, as depicted in Figure 10.26.

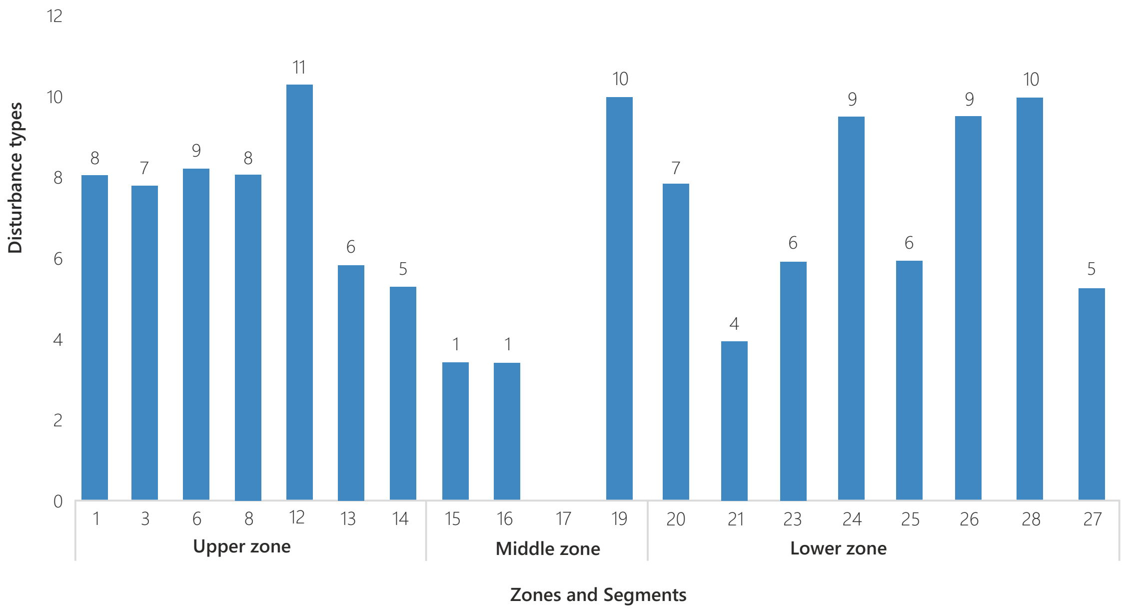


Figure 10.25 Frequency of various anthropogenic disturbances in different zones and segments of the Godavari River

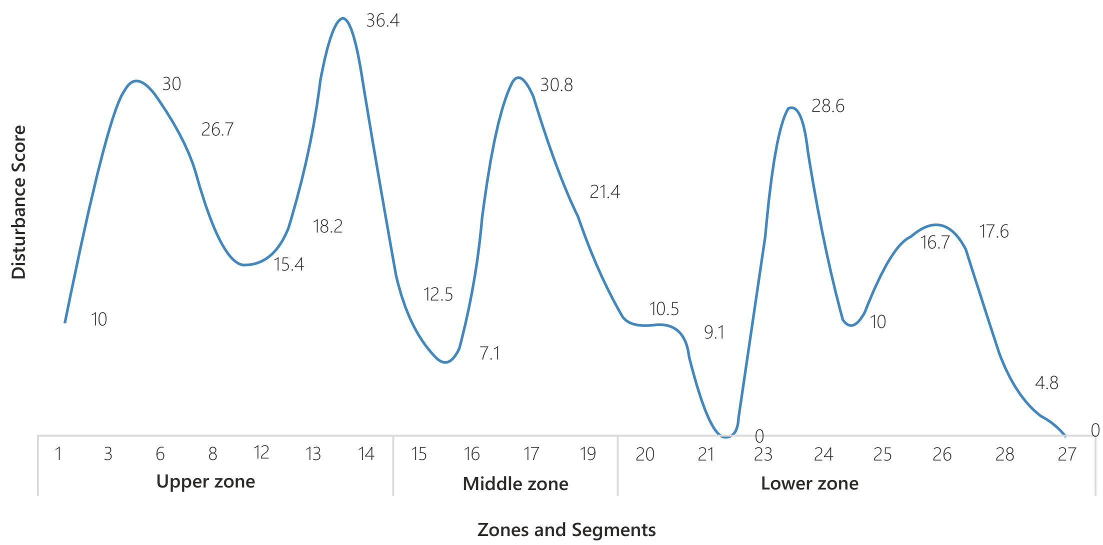


Figure 10.26 Scores of various anthropogenic disturbances in different zones and segments of the Godavari River

10.6. Status of Pollution

10.6.1 Water Quality

Water quality parameters were analyzed at seventeen locations viz., Trimbak, Chakratirth, Odha, Copargaon, Paithan, Pathri, Nanded, Kandapurthi, Gangama Temple, Dharmapuri, Mancherial, Kaleshwaram, Bhadrachalam, Polavaram, Rajamundri, Kapileshwara, and Yanam. The Godavari River exhibited temperature variations ranging from 20.6°C to 28.2°C. The pH levels ranged from 7.93 to 9.26, while salinity levels varied from 0.08 to 22.17 ppt. The dissolved oxygen (DO) content ranged from 1.17 to 14.2 mg/L. Total dissolved solids (TDS) ranged from 11.6 to 22919 mg/L, and conductivity levels varied from 167.6 to 36420 µs/cm. Additionally, nitrate levels in the study ranged from 0.41 to 40.53 mg/L. During the present study, all the observed parameters such as pH, Conductivity, Salinity, Nitrate and TDS were higher than the recommended limits of USEPA Aquatic Life Quality Criteria (Table 10.3).

Table 10.3 Water quality parameters studied in the Godavari River

Parameters	Upper Zone	Middle Zone	Lower Zone	Overall	USEPA's Aquatic Life Water Quality Criteria (1998)
Temp. (°C)	20.6-24.1	23.3-27.2	25.2-28.2	20.6-28.2	NA
pH	7.93-9.02	8.95-9.26	8.34-9.24	7.93-9.26	6.5-8.5
DO (mg/L)	1.17-14.2	7.29-10.66	5.88-10.04	1.17-14.2	≥ 5
Conductivity (µS/cm)	167.6-2120	471.2-664	253.6-36420	167.6-36420	150-500
Salinity (ppt)	0.08-1.12	0.22-0.31	0.12-22.17	0.08-22.17	<0.5
Nitrate (mg/L)	0.57-3.92	0.76-0.97	0.41-40.53	0.41-40.53	<10
TDS (mg/L)	11.6-1423.5	302.9-422.5	162.5-22919	11.6-22919	500

10.6.2. Heavy metal pollution

a. Heavy metal pollution in water

Analysis of the heavy metal in the water samples indicated presence of Chromium (3.19-10.56 mg/L), Cobalt (0.18-1.41 mg/L), Nickle (2.79-6.52 mg/L), Copper (0.9-4.15 mg/L), Zinc (1.95-24.67 mg/L), Arsenic (0.2-1.07 mg/L), Cadmium (0.05-6.79 mg/L), Mercury (0-0.13 mg/L), Lead (1.13-5.06 mg/L) (Table 10.4). Among the recorded heavy metals in the water of the Godavari River, the concentrations of zinc, mercury, lead, and cadmium exceeded the permissible levels established by the Canadian and US EPA Water Quality Guidelines. Cadmium concentrations were heightened at ten locations, with the highest recorded level in Nanded at 6.795 mg/L. Similarly, mercury levels were higher at all fifteen sample locations, except for Mancherial (0.020 mg/L) and Rajahmundry (0.000 mg/L). The highest concentration of lead was observed in Paithan at 5.060 mg/L, while zinc levels peaked at Mancherial with a concentration of 24.670 mg/L (Table 10.4, Figure 10.27).

Table 10.4: Heavy metal concentration (µg/L) in water samples recorded in different zones of the Godavari River

Heavy metals	Upper Zone	Middle Zone	Lower Zone	Overall	CWQGs (For aquatic life) µg/L	US-EPA (For aquatic life) µg/L	WHO guidelines (Drinking Water)
Cr	5.61-10.56	4.28-8.52	3.19-8.51	3.19-10.56	NA	NA	50
Co	0.18-0.73	0.22-1.41	0.23-0.36	0.18-1.41	NA	NA	NA
Ni	3.4-6.52	3.28-5.6	2.79-5.15	2.79-6.52	NA	52	70
Cu	1.12-4.15	1.17-3.69	0.9-2.02	0.9-4.15	NA	9	2000
Zn	2.92-15.8	3.43-24.67	1.95-4.91	1.95-24.67	7	120	NA
As	0.2-0.85	0.6-1.07	0.38-0.77	0.2-1.07	5	150	10
Cd	0.07-6.79	0.07-0.14	0.05-0.16	0.05-6.79	0.09	NA	3
Hg	0.03-0.11	0.02-0.1	0-0.13	0-0.13	0.026	0.77	6
Pb	2.15-5.06	2.01-3.66	1.13-3.68	1.13-5.06	NA	2.5	10

NA: Not available

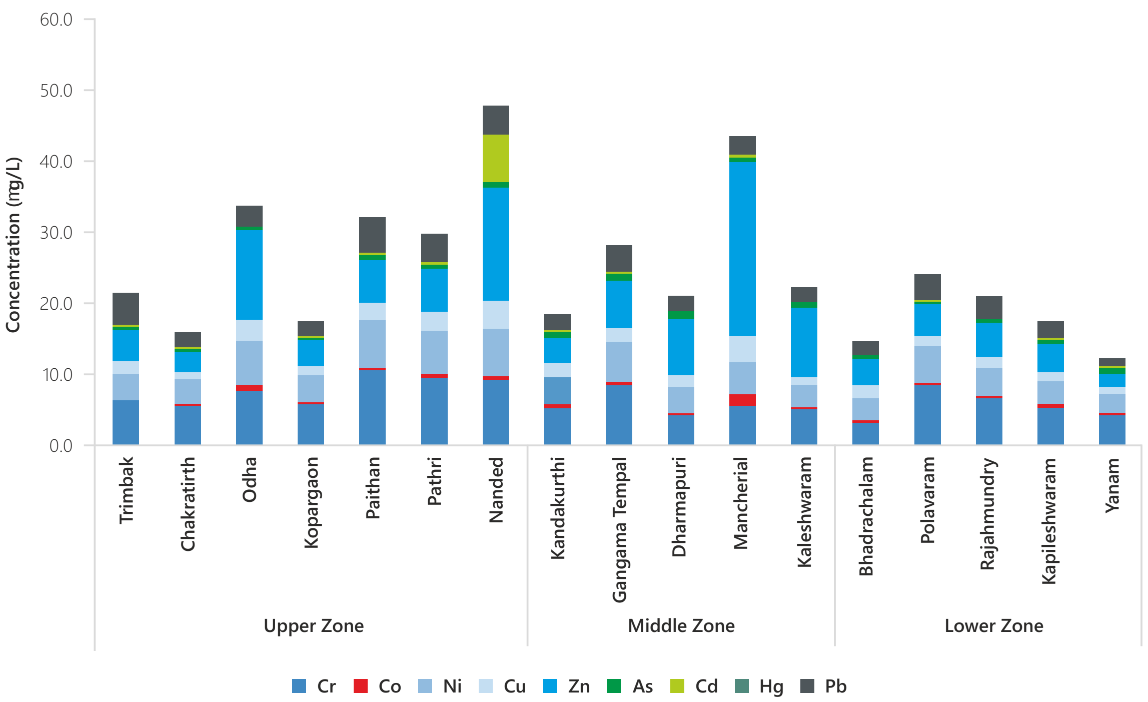


Figure 10.27 Heavy metal concentration recorded at various sampling sites in the Godavari River, India

b. Spatial mapping and identification of heavy metal hotspots in water

The spatial mapping of heavy metal hotspots in the Godavari River reveals significant contamination across various stretches of the river, with notable pollution levels in both the upper and middle zones. In the upper zone, contamination stretches from Maharashtra Prabodhan Seva Mandal, Lokmanya Nagar, Shivaji Nagar, Nashik to Nandur Madhymeshwar, spanning a distance of 58.10 km. Another stretch from Shree Chakradhar Swami Mandir, Jamgaon, Gangapur to Bhawani Mandir, Hasnapur covers 112.32 km, and further down, the stretch from Hasnapur, Ahilyanagar to Mahadev Mandir Khadki, Nanded extends 220.45 km, indicating significant heavy metal contamination. The middle zone extends from Karimnagar, Telangana to Sri Gowthameshwara Temple, Telangana, covering a distance of 56.76 km (Table 10.5, Figure 10.28).

Table 10.5 Polluted stretches in the Godavari River, India

Zone	Location		District	State	Km	Total Km
	From	To				
Upper	Prabodhan Seva Mandal, Lokmanya Nagar	Shivaji Nagar, to Nandur Madhymeshwar	Nashik	Maharashtra	58.10	390.87
	Shree Chakradhar Swami Mandir, Jamgaon, Gangapur	Bhawani Mandir, Hasnapur	Aurangabad, Sindhudurg	Maharashtra	112.32	
	Hasnapur, Ahilyanagar	Mahadev Mandir Khadki, Nanded	Ahilyanagar, Nanded	Maharashtra	220.45	
Middle	Karimnagar	Sri Gowthameshwara Temple	Karimnagar, Peddapalli	Telangana	56.76	

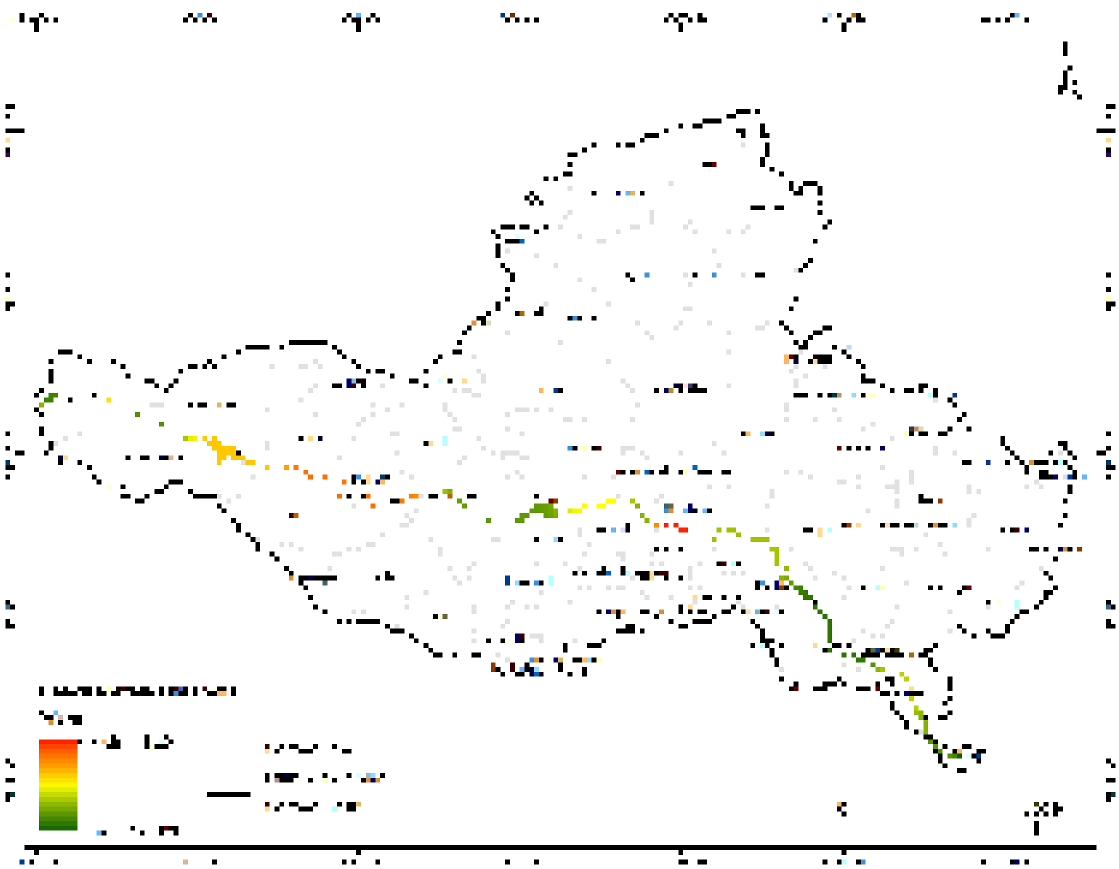


Figure 10.28 Spatial distribution of heavy metal pollution stretches in Godavari River, India

c. Heavy metal pollution in sediment

Assessment of the heavy metal in the sediment samples indicated the presence of Chromium (8.60-39.63 mg/kg), Cobalt (2.61-14.62 mg/kg), Nickle (4.26-26.37 mg/kg), Copper (3.39-30.00 mg/kg), Zinc (3.58-31.49 mg/kg), Arsenic (0.00-0.84 mg/kg), Cadmium (0.00-0.23 mg/kg) Mercury (0.00-0.04 mg/kg), Lead (1.53-10.58 mg/kg) (Table 10.6). Among the concentrations of various heavy metals recorded in sediment samples from the Narama River, Chromium (Cr), Cobalt (Co), Nickel (Ni), Copper (Cu), Zinc (Zn), Arsenic (As), Cadmium (Cd), and Mercury (Hg) Among these, Cobalt, Copper, Zinc, Arsenic, Selenium, Cadmium, Mercury, and Lead were within permissible limits. However, Chromium was beyond the permissible limit of all stations set by the Canadian Sediment Quality Guidelines (Table 10.6, Figure 10.29).

Heavy metals	Upper Zone	Middle Zone	Lower Zone	Overall	Canadian Sediment Quality Guidelines for the Protection of Aquatic Life (mg/kg)
Cr	8.6-39.63	10.22-16.57	12.14-18.16	8.6-39.63	37.3
Co	7.86-14.62	2.61-6.92	3.93-6.09	2.61-14.62	NA
Ni	10.58-26.37	4.26-11.48	5.05-11.21	4.26-26.37	NA
Cu	15.86-30	3.39-17.02	7.44-14.48	3.39-30	35.7
Zn	14.26-31.49	3.58-14.81	6.7-12.03	3.58-31.49	123
As	BDL-0.6	0.49-0.84	0.41-0.83	0-0.84	5.9
Cd	0.01-0.23	0-0.02	BDL-0.01	0-0.23	0.6
Hg	0-0.04	0-0.02	0.01-0.01	0-0.04	0.17
Pb	2.85-10.39	1.53-10.58	3.09-8.55	1.53-10.58	35

Table 10.6 Heavy metal concentration (mg/kg) in sediment across different zones of the Godavari River

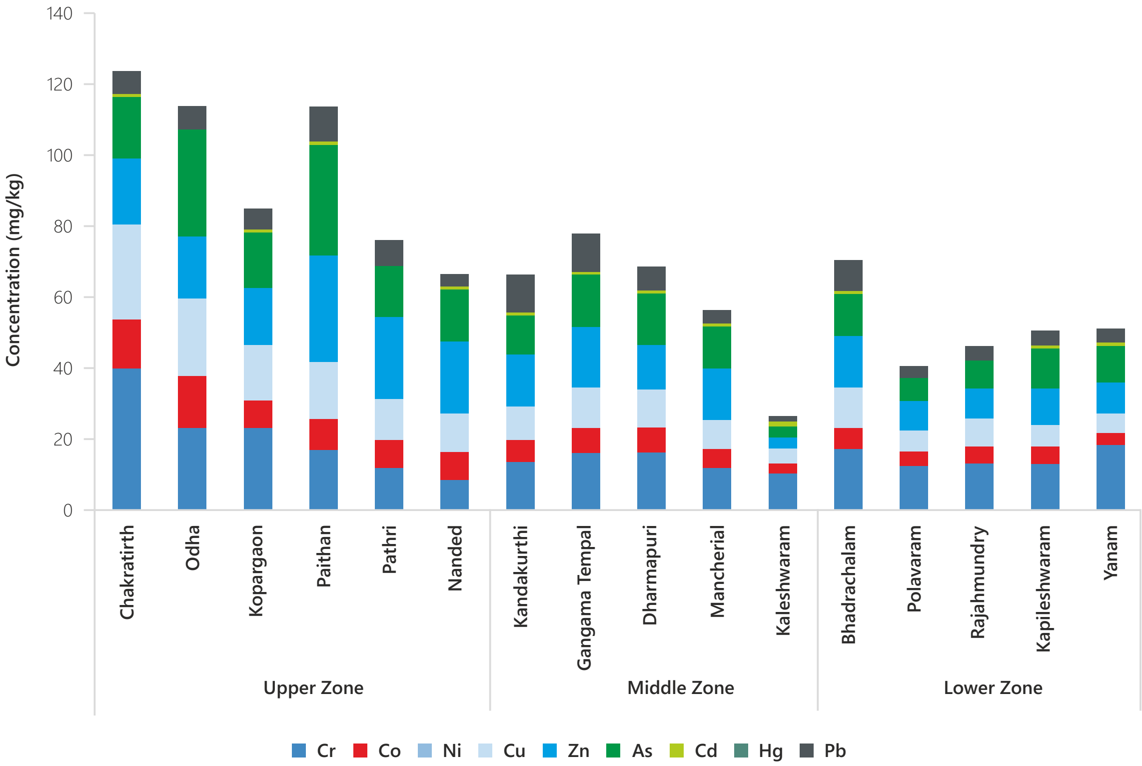


Figure 10.29 Heavy metal concentration in sediment recorded at various sampling sites in the Godavari River

d. Spatial mapping and identification of heavy metal hotspots in sediment

The spatial mapping of Heavy Metal in Sediment across the Godavari River, India, highlights key pollution stretches in the Upper Zone. In the upper zone, a significant stretch of 300.86 km extends from Mahadev temple, Trimbakeswar to Jogladevi Maharashtra, indicating elevated levels of Heavy Metal Contamination (Table 10.7, Figure 10.30).

Table 10. 7 Polluted stretches in the Godavari River, India

Zone	Location		District	State	Km
	From	To			
Upper Zone	Mahadev temple, Trimbakeswar	Jogladevi	Nashik, Jalna	Maharashtra	300.86 km

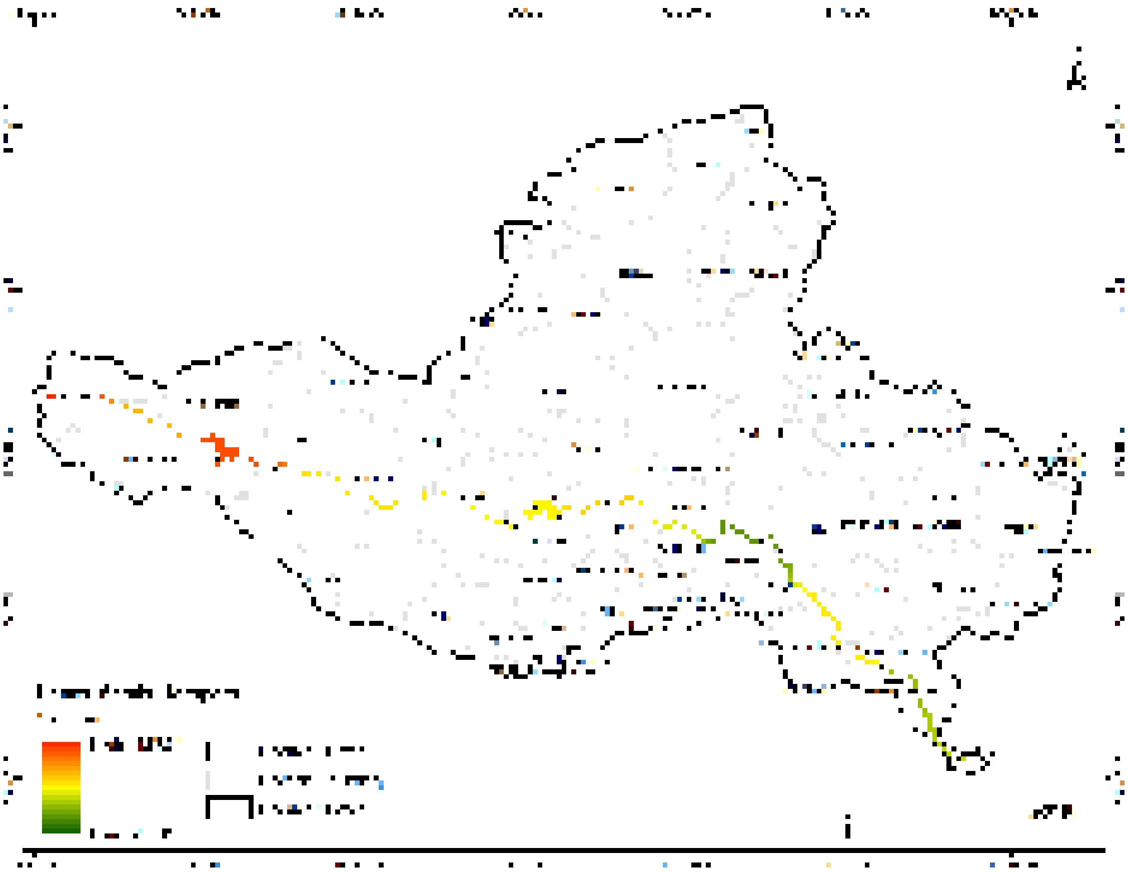


Figure 10.30 Identification of heavy metal hotspot in sediment of the Godavari River, India

10.6.3. EDCs Pollution

a. EDCs pollution in water

Analysis of the Endocrine Disrupting Chemicals in the water samples indicated presence Phthalate esters (748.52-2527.78 ng/L), OCPs (0-5.18 ng/L), Pyrethroid (0-82.08 ng/L), Pharmaceuticals (1.28-30.93 ng/L) Bisphenol A (0-57.8 ng/L), Hormones (0-2.52 ng/L), HPCP (4.21-11.47 ng/L) throughout river (Table 10.8). The spatial distribution of contaminants across various sites reveals significant variations in pollutant concentrations. Dharmapuri recorded the highest levels of PAEs (2527.78ng/L), while Odha exhibited notable pyrethroid contamination (82.08 ng/L). Additionally, Odha had the highest pharmaceutical pollutant concentration (30.93ng/L). The levels of bisphenol A (BPA) were highest at Dharmapuri (39.68 ng/L) and Bhadrachalam (32.29 ng/L). Hormonal pollutants peaked at Mancherial (1.67ng/L) and Nanded (1.62ng/L). Lastly, HPCP concentrations were prominent at Kopargaon (11.47 ng/L), Nanded (11.46 ng/L), and Kaleshwaram (10.46 ng/L). Overall, the data identifies Dharmapuri, Odha, and Bhadrachalam as high-priority sites for environmental management due to their elevated pollutant levels across multiple categories (Table 10.8, Figure 10.31).

Compound	Upper Zone	Middle Zone	Lower Zone	Overall
PAEs (Phthalate esters)	748.52-2306.91	824.95-2527.78	825.55-1534.09	748.52-2527.78
OCPs (Organochlorine pesticides)	0-3.11	0-5.1	1.5-5.18	0-5.18
Pyrethroid	0-82.08	0-0	0-5.62	0-82.08
Pharmaceuticals	1.28-30.93	2.42-7.42	1.73-6.37	1.28-30.93
BPA (Bisphenol A)	0-57.8	4.19-32.29	17.54-39.68	0-57.8
Hormones	0.88-2.52	0-1.67	0-0.91	0-2.52
HPCP (Health and personal care products)	4.21-11.47	7.23-10.46	5.43-10.18	4.21-11.47

Table 10.8 EDCs Concentration (ng/L) in water across different zones of the Godavari River

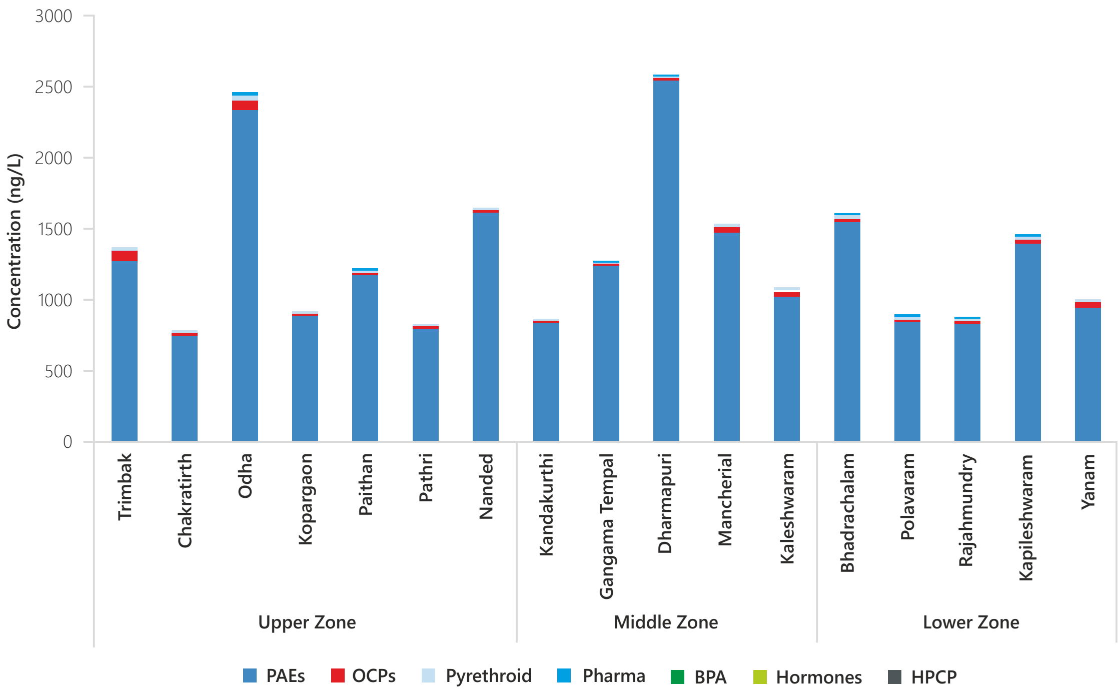


Figure 10.31 EDCs Concentration in water recorded at various sampling sites in the Godavari River

b. Spatial mapping and identification of EDCs in water

The spatial mapping of Endocrine Disrupting Chemicals (EDCs) in water across the Godavari River, India, highlights key pollution stretches in both the upper and middle zones. In the upper zone, a significant stretch of 64.96 km extends from Gangapur Road (Rd.), Nashik to Karanji Khurd (Kh.), Maharashtra, indicating elevated levels of EDC contamination. In the middle zone, a stretch of 37.38 km from Ellamma Temple, Arepalle to Sri Raja Rajeshwara Swamy Temple, Arepalle, Mittapally, Telangana shows notable EDC presence (Table 10.9, Figure 10.32).

Zone	Location		District	State	Km	Total km
	From	To				
Upper	Gangapur Rd	Karanji Kh.	Nashik	Maharashtra	64.96	102.34
Middle	Ellamma Temple, Arepalle Sri Raja Rajeshwara Swamy Temple, Arepalle	Mittapally	Karimnagar, Medak	Telangana	37.38	

Table 10.9 Polluted stretches in the Godavari River, India

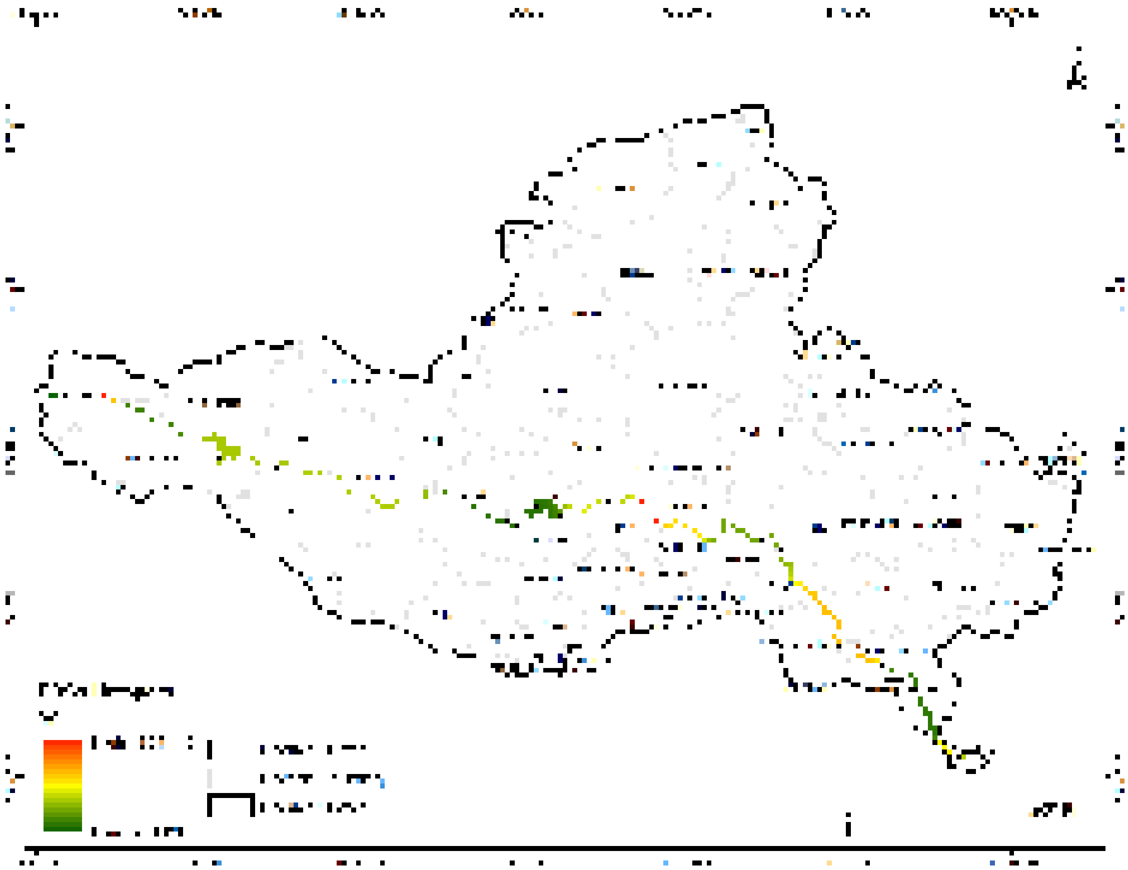


Figure 10.32 Identification of EDCs hotspot in the water of the Godavari River, India

c. EDCs pollution in sediment

In our current study, have observed several Endocrine Disrupting Chemicals such as different Phthalate esters (25.73-8347.44 ng/g), OCPs (0.15-4.36 ng/g), OPs (0.45-36.61 ng/g), Pharmaceuticals (0.01-0.09 ng/g), Bisphenol A (5.53-29.1 ng/g), HPCP (0-0.52 ng/g) throughout river (Table 10.10). The spatial distribution of EDCs (Endocrine-Disrupting Compounds) in sediment samples, highlights significant site-specific variations. Nanded recorded the highest levels of phthalate esters (8347.44 ng/g). For organochlorine pesticides (OCPs), the maximum concentration was found at Nanded (4.36 ng/g). Organophosphates (OPs) peaked at Chakratirth (36.61 ng/g), with Kopargaon (34.92 ng/g) and Nanded (33.83 ng/g) showing similarly elevated levels. Pharmaceutical concentrations were highest at Chakratirth, Pathri, and Kandakurthi, each recording 0.06 ng/g, indicating localized pollution from untreated wastewater. Bisphenol A (BPA) exhibited maximum concentrations at Mancherial (29.10 ng/g), followed by Odha (25.08 ng/g) and Dharmapuri (24.04 ng/g). Finally, HPCP levels were highest at Kopargaon (0.52 ng/g) and Gangama Temple (0.35 ng/g), signifying areas of higher domestic and industrial pollutant discharge (Table 10.10, Figure 10.33).

Table 10.10 EDCs concentration (ng/g) in sediment across different zones of the Godavari River

Compound	Upper Zone	Middle Zone	Lower Zone	Overall
PAEs (Phthalate esters)	2828.6-8347.44	25.73-3111.08	40.31-110.98	25.73-8347.44
OCPs (Organochlorine pesticide)	1.34-4.36	0.17-1.58	0.15-0.21	0.15-4.36
OPs (Organophosphorus pesticide)	24.69-36.61	0.49-8.63	0.45-0.62	0.45-36.61
Pharmaceuticals	0.01-0.06	0.02-0.06	0.05-0.09	0.01-0.09
BPA (Bisphenol A)	5.53-25.08	8.53-29.1	9.29-15.13	5.53-29.1
HPCP (Health and personal care products)	0.14-0.52	0.03-0.35	0-0.29	0-0.52

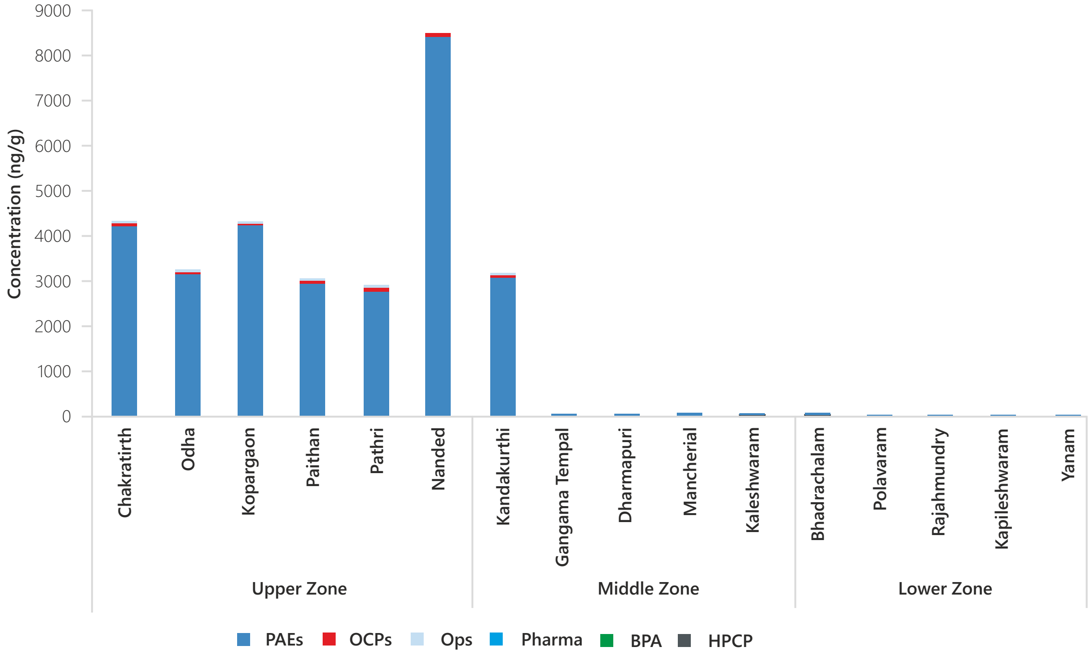


Figure 10.33 EDCs concentration in sediment recorded at various sampling sites in the Godavari River

d. Spatial mapping and identification of EDCs in sediment

The spatial mapping of Endocrine Disrupting Chemicals (EDCs) in sediment across the Godavari River, India, reveals significant pollution stretches in the upper zone. The contamination in sediments is most prominent in the stretch between Talwade Trimbak, Maharashtra to Kesington Club, Nashik, Maharashtra, covering a distance of 28.10 km. Another polluted stretch extends from Karanji Kh., Maharashtra to Guptai Mata Mandir, Newasa, Maharashtra, spanning 95.7 km. The longest stretch is found between Dhananjay Khote Home to Shaheen Academy, Nanded-Waghala, Maharashtra, which spans 275.67 km. These findings indicate extensive EDC contamination in the sediment along the river, highlighting areas where pollutants may accumulate and persist for extended periods. (Table 10.11, Figure 10.34).

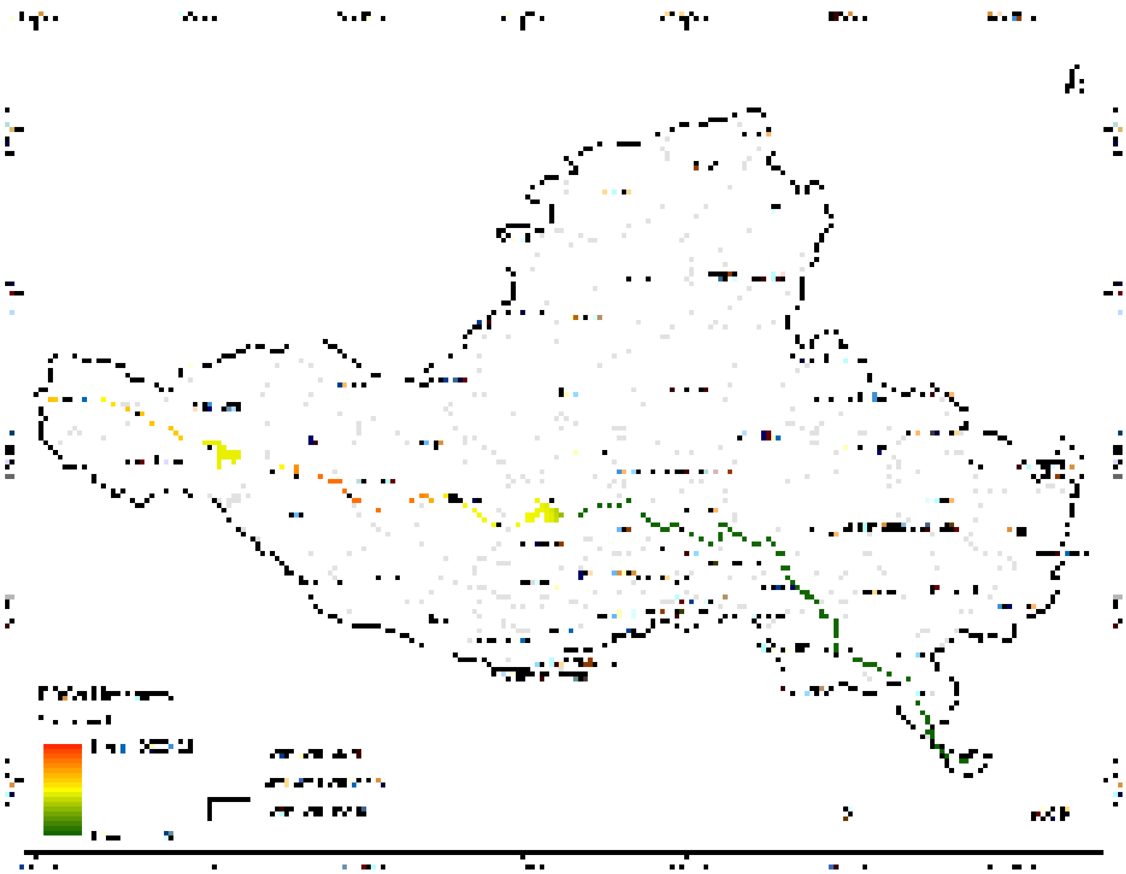


Figure 10.34 Identification of EDCs Hotspot in Sediment of the Godavari River, India

Table 10. 11 Polluted stretches in the Godavari River, India

Zone	Location		District	State	Km	Total km
	From	To				
Upper	Talwade Trimbak	Kesington Club	Nashik	Maharashtra	28.10	399.47
	Karanji Kh.,	Guptai Mata Mandir, Newasa,	Nashik Ahilyanagar		95.7	
	Dhananjay Khote Home	Shaheen Academy Nanded-Waghala	Nanded		275.67	

10.6.4 Bioaccumulation of heavy metals and EDCs in Fish Biota

Among heavy metals, *Systomus sarana* from the middle zone exhibits the highest Cr concentration (47.52 mg/kg) followed by *Labeo calbasu* (7.63 mg/kg) from the middle zone of the river. Zn concentrations were markedly high in *Oreochromis niloticus* (14.54 mg/kg) and *Labeo calbasu* (14.9 mg/kg). Cu concentrations were highest in *Oreochromis niloticus* (0.85 mg/kg) than other fish biota from the Godavari River. Conversely, other heavy metals (Pb, Hg, Cd, As, Ni, and Co) remained below 0.3 mg/kg in all samples (Figure 10.35a).

Among EDCs, the highest concentration was observed in *Ompok bimaculatus* from the upper zone (176.91 ng/g), followed by *Labeo calbasu* (79.87 ng/g) and *Systomus sarana* (77.59 ng/g) from the middle zone (Figure 10.35b). Bisphenol A was 4.16 ng/g in *Ompok bimaculatus* from the upper zone. PCB residues were minimal across all samples. Pharmaceuticals were consistently present at low concentrations (0.08-0.23 ng/g), with *Channa striata* and *Cirrhinus mrigala* showing higher levels. OCPs was highest in *Ompok bimaculatus* (3.93 ng/g). OPs were relatively higher in *Channa striata* (0.31 ng/g) and *Ompok bimaculatus* from the middle zone (0.94 ng/g) (Figure 10.35b).

Higher concentrations of Cr and Zn than regulatory limits [Food Safety and Standards (Contaminants, Toxins, and Residues) Regulations, 2011], PAEs and Bisphenol A contamination in fish species from the Godavari River indicates ecological stress and potential disruption of aquatic food webs. Spatial trends reveal hotspot zones requiring targeted ecological intervention. Routine monitoring and public advisories are essential to safeguard human health. Higher bioaccumulation in *Systomus sarana* and *Ompok bimaculatus* may be attributed to their benthic habitat and feeding on sediment-associated prey, increasing exposure to persistent contaminants.

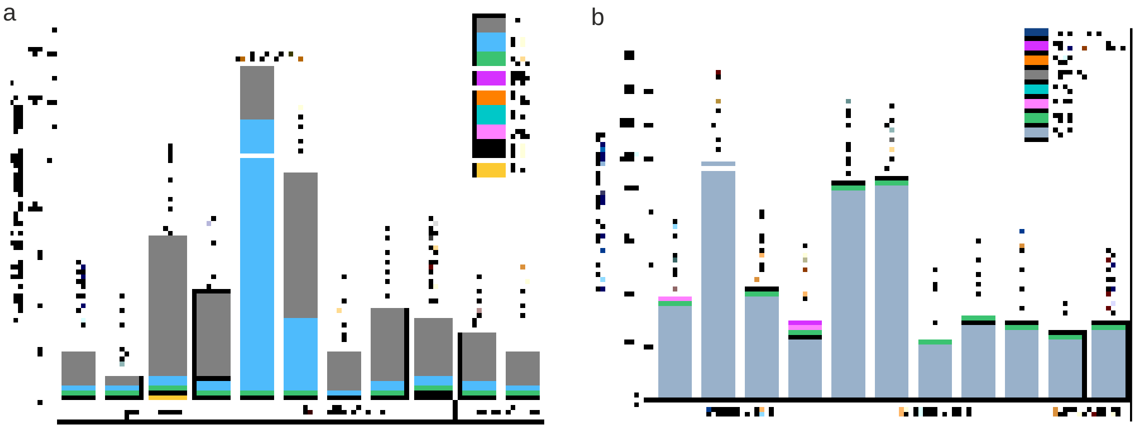


Figure 10.35 Heavy metals (a) and EDCs (b) concentration in fish biota collected from the Godavari River

10.7 Discussion

The Godavari River basin is renowned for its diverse range of plants and animals that thrive in and around its waters, contributing to its rich biodiversity. The river supports various aquatic life forms, including different species of fish and freshwater turtles. Additionally, the region serves as a habitat for migratory birds, further enhancing its ecological significance. However, the river's ecosystem faces numerous challenges by these anthropogenic pressures, such as grazing, water extraction, fishing, waste disposal, mining, ferry boats, ranging dogs, bathing ghats, religious ghats, developmental areas, cremation grounds, brick kilns, and aquatic vegetation, pose a threat to the survival of aquatic species and may have adverse effects on their populations.

A report from (CIFRI, 2020) specified that Godavari River supports 104 fish species from 37 families which included both freshwater and estuarine areas. In accordance with the presence of 6 exotic species viz., *Ctenopharyngodon idella, Oreochromis mossambicus, Oreochromis niloticus, Clarias gariepinus, Cyprinus carpio* and *Pterygoplichthys disjunctivus* and 2 Endangered species viz., *C. magur* and *Silonia silondia* and 4 Near Threatened species viz., *Anguilla bengalensis, Chitala chitala, Ompok bimaculatus* and *Wallago attu*. The Godavari River is an important habitat for *Silonia childreni*, a highly threatened catfish species occurring in the large river systems of peninsular India (Ray et al., 2022) Therefore, the population of these threatened and almost threatened species could be destroyed by rampant fishing. Though direct evidence could not be obtained on the increased effort, the following indications are available the fishermen exploiting the stretch of the river are predominantly full-time operators. They are skilled in river fishing and depend fully on the river for their sustenance (CIFRI, 2020).

Also, the extraction of sand and pebbles from the river system is one of the most serious stresses on the river environment (Rovira et al., 2005; Kondolf, 1994), and it may lead to irrecoverable damages (Bull and Scott 1974; Collins and Dunne 1987; Sandecki 1989; Kondolf and Swanson 1993; Kondolf 1994; Pakalnis et al.,1994; Kondolf 1997; Weeks et al., 2003; Wyzga et al., 2005; Erskine 2008). So, such damages may include destruction of riverine vegetation, bank erosion, pollution of water sources and groundwater depletion in wells. A stable riverbed is one of the conditions that ensure the (long-term) survival of many species. The sand layer on the solid riverbed is a hospitable environment for many microorganisms. Removal of the sand means instability and a loss of habitat for these organisms (Zou et al., 2019). Aquatic vegetation and microorganisms play an important role in maintaining the balance and health of the river's biological environment and when the balance in this ecosystem is disturbed it can be pushed to or crossed over a tipping point (Padmalal et al., 2014). The extraction of sand stirs up the water and increases turbidity. This, in turn, blocks sunlight and reduces respiration and photosynthesis, but can also block the respiratory organs of aquatic animals (Maya et al., 2014; Barman et al., 2019a; Barman, et al., 2019b). When deposited, the stirred-up particles like silt and clay form a blanket on the river bed which can smother microorganisms such as diatoms, macroinvertebrates, benthic algae, or fish eggs (Padmalal et al., 2014; Barman et al., 2019a; Barman et al., 2019b). Sunilkumar (2002) studied the average abundance of benthic organisms in the Achonkovil River, India, and showed that there are significantly fewer benthic organisms in the disturbed area than there are in the undisturbed area. Similar results were found in the South Bengal River, India, where on the catastrophic effects of sand mining had indeed induced a substantial decline of macroinvertebrates (Bhattacharya et al., 2019; Zou et al., 2019). These organisms are at the bottom of the food chain and the repercussions of such a decline can be felt many trophic levels higher, for example for humans who consume fish that feed on these macroinvertebrates. Also, many terrestrial animals such as insects that feed on aquatic life will be affected (Padmalal et al., 2014). The disturbed ecosystem balance can even favour invasive species. Apart from the fauna, the mining also takes its toll on the flora. A direct way the flora is impacted is through the destruction of vegetation using bar skimming and transport-related infrastructure. This not only destroys the habitats above ground but also below ground. Additionally, water abstraction was noted throughout the Godavari River, which further affected the river's flow.

The pollution of river Godavari in India is more critical and severe as a huge amount of pollution load discharged by bathing, washing of clothes and vehicles, sewage from the municipality, garbage from the vegetable market and mixing of cremation ash is directly with the water, resulting into the change in physic-chemical and biological characteristics of river water ultimately results into making it unsuitable for drinking purpose, agricultural use and posing serious threat to survival of aquatic biota and terrestrial life (Bhalla and Sekhon 2010). In the present study waste dumping was remarkably very high in segment 20 of the lower zone. In sampling segments 15 and 19, there are sources of industrial outlets releasing effluent directly into the Godavari River as well. So, this polluted water may also pose a serious negative impact on the ecologically sensitive Nandur Madhmeshwar bird sanctuary, which is a Ramsar site as well. Additionally bathing ghats contributes significantly towards deterioration of water quality (Jani et al., 2018; Botekar 2012; Shackley 2001). In addition to point and non-point sources of pollution, the Godavari basin has undergone several developmental activities such as industrialization, urbanization, irrigation, damming, shipping, and waterways developments only to meet the demands of the growing population. In the present study, the highest site for developmental activity includes the construction of dams, Barrages, bridges, etc, observed in segment 19 of the middle zone. Through the years, industries have rapidly mushroomed in the basin. The basin's major urban centres are Nagpur, Aurangabad, Nashik, and West Godavari. The districts of Aurangabad and Nashik have many industries, especially automobiles. Apart from this, the industries in the basin are mostly based on agricultural products such as rice milling, cotton spinning and weaving, and sugar and oil extraction. Cement and some small engineering industries also exist in the basin.

Beyond point and non-point sources, the Godavari basin has undergone rapid development to meet rising population demand. Segment 19 of the middle basin shows the highest intensity of infrastructure development including dams and barrages. Industrial growth, particularly of automobile in Nagpur, Aurangabad, Nashik, and West Godavari is evident. Other industrial sectors include, agro-based sectors, cement, and other engineering industries. To support agricultural and industrial developments several irrigation projects and dams have been established in the basin. A total of 3200 dams were constructed in India, in Godavari River basin, has the highest number (350) of major/ medium dams and barriers in India constructed through the year 2012. Among irrigation projects, notably the Polavaram dam is affecting the state of Andhra Pradesh but also has minor effects on the adjacent states of Orissa and Chhattisgarh (Verma et al., 2022). Due to the construction of the dam and the area getting submerged, the Polavaram Project has a substantial environmental impact. As a result, the well-known tourist site Papikondalu has fully sunk. Thus, habitat loss is contributing to the decline of tigers and sloth bears. The richness of the area will be disrupted as a result of the loss of species. So, in the Godavari River, activities that alter the riverine ecology will also affect vital nesting and basking habitats of freshwater turtles such as the Leith's softshell turtle (*Nilsonnia leithii*), Asian giant softshell turtle (*Pelochelys cantorii*), Narrow headed softshell turtle (*Chitra indica*) and Indian tent turtle (*Pangshura tentoria*) in the Godavari River. The mass nesting sites of the Olive Ridley turtle (*Lepidochelys olivacea*), in the Godavari delta are likely to be damaged by increasing developmental activities in the delta region. Increasing activities that encroach upon mangrove forests will directly affect the habitat of Mammals such as the fishing cat and the Smooth-coated otter inhabiting the Coringa Wildlife Sanctuary.

In aquatic environments, metals have been termed as conservative pollutants because once added to the environment, they prevail for a long time in the absence of removal by processes of oxidation, precipitation, etc (Besada et al., 2002). Hence, heavy metal contamination of freshwater environments is a major cause of concern as it may worsen the natural habitats by diminishing eco-sensitive species or by elimination of the commercial species and also pose a significant health hazard to humans (Eja et al., 2003). An increase in heavy metal concentration in water results in histological, biochemical, morphological, and physiological changes as well as behavioural changes (Kulkarni and Shrivastava 2000). Several studies have reported that the Godavari River has been heavily contaminated with heavy metals for decades (Bhalla and Waykar 2013; Patil and Kaushik 2016; Prasad et al., 2019). Heavy metal pollution in the Godavari River occurs in various forms from a wide range of sources. Besides industrial effluents, waste disposal, and agricultural runoff, idol immersion in water bodies are major reasons that contributed. Nowadays, paints used to colour these idols contain numerous heavy metals such as Zinc, Chromium, and Lead (Bhattacharya et al., 2014). More specifically, red, 60 blue, orange, and green colours contain Zinc oxide, Chromium, and lead, which are potential carcinogens. Heavy metals such as Lead and Chromium are also added to water bodies through Sindoor (Bhattacharya et al., 2014). The floating materials released from idols in water bodies after decomposition result in eutrophication, elevating the acidity and concentration of heavy metals. Moreover, the Godavari River is threatened with heavy metal pollution.

The pollution of river Godavari in India is more critical and severe as a huge amount of pollution load discharged by bathing, washing of clothes and vehicles, sewage from the municipality, garbage from the vegetable market and mixing of cremation ash directly with the water, resulting into the change in physicochemical and biological characteristics of river water ultimately results into making it unsuitable for drinking purpose, agricultural use and posing a serious threat to survival of aquatic biota and terrestrial life (Bhalla and Sekhon, 2010).

The water quality of the Godavari River exhibits significant variations across its upper, middle, and lower zones. These differences arise from both natural processes and human activities, such as industrialization and agriculture. Key parameters, including temperature, pH, dissolved oxygen (DO), and total dissolved solids (TDS), indicate elevated levels in certain areas, which highlight the river's vulnerability to pollution. For instance, the DO concentration at Nanded was alarmingly low at 1.17 mg/L. This low level suggests varying degrees of pollution or other factors affecting oxygen levels in the region. Studies have shown that the portion of the river in Nanded is severely impacted by pollutants, particularly urban waste discharged from both banks as the river flows through the city.

In addition to point and non-point sources of pollution, industries have rapidly proliferated in the basin. Water and sediment samples from the Godavari River have been found to contain several heavy metals, including Arsenic (As), Cadmium (Cd), Copper (Cu), Cobalt (Co), Chromium (Cr), Mercury (Hg), Nickel (Ni), Lead (Pb), and Zinc (Zn). Similar findings have been reported in other rivers of India, such as the Barak, Ganga, Yamuna, Mahanadi, Cauvery, Narmada, and Periyar Rivers (Table 10.12).

The concentration of zinc exceeded the permissible limit at certain specific stretches viz., Odha and Nanded are in the upper zone, and Dharmapuri Mancherial, Kaleshwaram is in the middle zone. Zinc contamination in freshwater rivers in India results from both natural and human activities. Industrial discharges from sectors like mining, metal processing, and manufacturing often release zinc into nearby water bodies through untreated or inadequately treated effluents. Additionally, the use of zinc-containing fertilizers and pesticides in agriculture leads to runoff during heavy rains, further contributing to pollution. Domestic sewage, particularly when not properly treated, also adds to the contamination, as household products containing zinc make their way into rivers. While zinc can naturally leach into rivers from zinc-rich rocks and soil, this is generally a less significant source compared to the more prevalent human-induced activities (Archna Akhand et al., 2012). Zinc pollution in the Godavari River has significant ecological and health impacts. High zinc concentrations disrupt the gill function of fish, leading to fish kills and damaging the aquatic ecosystem. For humans, the contamination poses serious health risks, including gastrointestinal issues like nausea and vomiting from drinking polluted water, and long-term exposure can result in kidney and liver damage. In areas like Rajahmundry, where the river serves as a primary drinking water source, concerns about water safety due to industrial effluents and agricultural runoff have heightened, posing a threat to both public health and local livelihoods.

The concentration of cadmium was observed exceptionally high in the middle zone with alarming concentration recorded around Nanded. Human activities like waste disposal along the riverbanks, using river water for sanitation, laundry, and religious practices, contribute to the presence of chemicals such as phosphates, detergents, oil, and religious offerings in the water, potentially leading to cadmium pollution (NWCM, 2015). Moreover, applying fertilizers and irrigation can introduce cadmium into soil and water sources. Various industries, including pharmaceuticals, electroplating, rubber and plastics, tanneries, organic chemicals, and pesticides, release cadmium and other heavy metals through their wastewater, which can further contaminate water bodies through runoff from industrial areas (NWCM, 2015). There are 17 units of Metal-Based (Steel Fab), 122 Engineering Units, and 71 Electrical Machinery and transport equipment industries, including Shiva Fertilizer Ltd., Dhakani, Loha, Nanded, Maharashtra Krushi & Udyog Vikas Mahamandal, MIDC, IN Nanded. Therefore, a higher level of cadmium could be related to the presence of these industries in the Nanded region. Consumption of water contaminated with cadmium affect growth and compromised pigment contents of the organism, causing abnormal embryonic development, retarded cell cycle, increased apoptosis, and disruption of energy metabolism in fish (Edgar and Tham 2018; Yixia et al., 2020; Zamani-Ahmadmahmoodi et al., 2020; Chang-Hong et al., 2021). In humans, long-term exposure to cadmium can cause kidney damage, bone diseases, respiratory problems, and possibly an elevated risk of certain cancers.

The concentration of mercury in the Godavari River exceeded the permissible limits along its entire stretch, with specific areas such as Paithan in the upper zone, Kandakurthi in the middle zone, and Yanam in the lower zone showing particularly high levels. Higher levels of mercury in the Godavari River could be related to the coal mining in Adilabad, Karimnagar, Khammam, and Warangal districts (Telangana), Wardha Valley (Maharashtra), Additionally, Combined Cycle power plant, (Subbampeta, Andhra Pradesh), the Bhadradri thermal power station and the Ramagundam super thermal power station in Peddapalli district (Telangana) also contributed to the mercury contamination in the river. Mercury (Hg) accumulates in aquatic organisms, particularly in fish and shellfish, in the form of methylmercury in their bodies through the food chain. Methylmercury is a highly toxic compound that can cause damage to the central nervous system, leading to cardiovascular, respiratory, and other diseases (Li and Tse 2015; Mergler 2021).

The concentration of lead also exceeded the permissible limit in the entire stretch. An elevated level of lead was recorded in the stretches in Paithan (Upper zone) Gangama temple (middle zone) and Polavarm (lower zone). A higher level of lead in the river could be related to idol immersion during religious rituals (Bhattacharya et al., 2014; Bhattacharya et al., 2019). The idols in water bodies after decomposition result in eutrophication, elevating the acidity and concentration of heavy metals. Lead even at low concentration is known to cause serious health issues such as lowering IQ and disrupting development, in children and high blood pressure and infertility in adults. Studies determined that chronic lead exposure can be so lethal that metamorphosis, neurology, and other developmental progressions will be inhibited in aquatic organisms.

The sediment sample from Chakratirh has revealed chromium levels exceeding permissible limits, indicating severe pollution from human activities. This is mainly caused by industrial effluents, agricultural runoff, and municipal sewage. Chromium is a chemical element that is widely used in various industries and is primarily sourced from foundries involved in iron and steel production, electroplating industries, treatment facilities, inorganic chemical plants, as well as discharge from urban and residential areas (Gaur et al., 2005).

Therefore, the high concentration of chromium could be related due to the industrial discharge from various industries including Anuran Engineering Co. Pvt. Ltd., L. G. Balkrishnan & Bros. Ltd. (Waluj), Aurangabad Electricals Ltd., and Santosh Alloy Pvt. Ltd. (Paithan) among others. These industries are involved in activities such as aluminium pressure die casting, manufacturing of automobile electrical components, production of iron and steel chains, and nonalloy steel ingots (DCMSE, 2024). The higher level of chromium in the Godavari River may cause various pathophysiological defects, including allergic reactions, anaemia, burns, and sores, especially in the stomach and small intestine of fish (Nisha et al., 2016). Ingesting chromium from contaminated food (such as fish, vegetables, grains, fruits, or yeast) can pose noncarcinogenic health risks and may contribute to cancer development (Mohinuzzaman et al., 2018). Additionally, it can damage sperm and affect the male reproductive system in humans (Georgaki and Charalambous 2023; Hossini et al., 2022).

Similarly, the assessment of endocrine-disrupting chemicals (EDCs) in water and sediment further underscores the pervasive nature of pollution in the Godavari River. Assessment of the EDCs in the water and sediment sampled indicated the presence of the Phthalate esters (PAEs), Organochlorine Pesticides (OCPs), Organophosphate Pesticide (OPs), Pharmaceuticals, Bisphenol A, (BPA) Hormones, and Health and Personal Care Products (HPCP) throughout the river. Our results were in line with various studies highlighting in Ganga, Yamuna, and Brahmaputra, thus, it can be inferred that Godavari is also polluted from EDCs like other rivers of India (Table 10.13). Among various EDCs classes, the concentration of phthalate esters in water was maximum and it was followed by the Bisphenol A, PCP, Pyrethroid, Pharmaceuticals, OCPs, and Hormones. Moreover, phthalate esters were observed in high concentrations in sediment as well.

In the Godavari River, the highest concentration of phthalate esters-chemicals commonly used as plasticizers in various industrial and consumer products-was found in water samples collected around Dharampur. Meanwhile, sediment samples showed the maximum concentration of phthalate esters near Nanded in the upper zone of the river. Phthalates are the most widely used plasticizers globally and can be found in hundreds of products, including flexible polyvinyl chloride (PVC) items, perfumes, hair sprays, adhesives, floor and wall coverings, cable jacketing, automotive products, toys, medical tubing, blood storage bags, and food packaging materials. Since these plasticizers are not chemically bound to the products, they are easily released into the environment. This release occurs through various sources, including industrial and municipal wastewater, the land application of sewage sludge, the disposal of industrial and municipal solid waste, and leaching, migration, and evaporation during the use of these products (Lü et al., 2018; Luo et al., 2018; Yang et al., 2018).

Phthalate esters cause adverse developmental, metabolic, neurological, immune, and reproductive effects in organisms with BBP, DEHP, and DBP eliciting the most effects (Staples et al., 1997; Aarab et al., 2006; Arambourou et al., 2019; Zhang et al., 2021). In humans, when PAEs, combined with anti-androgen drugs, have been observed to accumulate in the male reproductive organs and may affect human reproductive development (Berman et al., 2009; Wang et al., 2012). Additionally, they are suspected to cause damage to liver, kidney, and thyroid gland tissues (Hinton et al., 1986).

Another class of endocrine-disrupting chemicals (EDCs) detected in the water and sediment of the Godavari River was organochlorine pesticides. The concentration of organochlorine pesticides in the water was highest in the middle zone, particularly around Kapileshwaram, while in the sediment, the highest levels were found in the upper zone, around Nanded. Kodavanti et al., (2014) highlighted that the discharge of waste or wastewater from industrial and agricultural activities is responsible for the occurrence of this pollutant in the river. The extensive use of these chemicals in agriculture raises significant concerns about their potential impact on ecosystems and wildlife. Furthermore, exposure to these substances can lead to serious health issues, including chronic conditions such as cancer, diabetes, obesity, and cardiovascular diseases. Aquatic species are particularly vulnerable, with reproduction, development, and behaviour being the most adversely affected (Kasonga et al., 2021).

The concentration of pharmaceuticals in the water sample was observed to be highest in the upper zone around Odha, and the sediment sample's highest concentration was observed in the lower zone around Polavaram. The concentration of pharmaceuticals in the water sample was observed to be highest in the upper zone around Odha, and the sediment sample's highest concentration was observed in the lower zone around Polavaram. The presence of pharmaceuticals particularly ibuprofen, which was dominated in the water and where in sediment Caffeine was highly dominated.

According to Marchlewicz et al., (2016), Ibuprofen is one of the most widely used and prescribed over-the-counter medicines globally. However, due to human activity, the concentration of this drug in the environment is increasing. When metabolized by humans and animals, Ibuprofen produces various metabolites, some of which are more toxic than the original molecule. The presence of Ibuprofen and its metabolites in wastewater treatment plants and water bodies is on the rise, posing a threat to rivers, lakes, oceans, soil, and groundwater. This drug is not completely metabolized after consumption and is excreted, leading to its uptake by plants and aquatic organisms. Its presence has been found to negatively impact fish spawning and increase the number of eggs in *Oryzias latipes* (Flippin et al., 2007). Even at low concentrations (250 ng/L), Ibuprofen has been shown to cause endocrine disruption in *Mytilus galloprovincialis*. Moreover, its presence caused the induction of antioxidative stress. The membrane damage in the digestive gland and lipid oxidation level increased in mussels was observed (Gonzalez-Rey and Bebianno, 2012). Considering these findings, it is crucial to develop more effective methods and advanced technologies for the removal of Ibuprofen from the environment.

Caffeine occurs naturally in approximately 60 plant species and it is a highly used stimulant contained in coffee, tea, caffeinated beverages as well as in several pharmaceutical products (Gilbert 1984; Buerge et al., 2003; Fent et al., 2006; Palo and Choudhury 2006; Moore et al., 2008). Globally, caffeine concentrations in numerous consumed products ranged from 36 to 804 mgL^{-1} in coffee; 17-551 mgL^{-1} in chocolates; 13-68 mgL^{-1} in ice tea drinks; 267-340 mgL^{-1} in energetic drinks; 15-448 mgL^{-1} in coffee-based beverages and 1002-1353 mgL^{-1} in food supplements (Korekar et al., 2020; Rudolph et al., 2012).

The main recognized sources of this psychoactive drug in the aquatic environment include wastewater excretory residues, inappropriate deposition of expired or unwanted caffeine-containing pharmaceutical products, manufacturing plant wastes, and hospital wastes, among others (Froehner et al., 2011; Cruz et al., 2016) . Based on a study of larvae of an endemic Neotropical catfish exposed to different concertation of caffeine skeletal deformations and reduced growth in the fish (dos Santos et al., 2022). Caffeine residues found in environmentally realistic concentrations can have detrimental effects on aquatic organisms. These residues have been discovered to induce oxidative stress, lipid peroxidation, neurotoxicity, alterations in energy reserves, and disruptions in reproduction and development. (Caffeine: Emerging contaminant of global rivers and coastal waters, mongabay.com). The existence of caffeine and other coffee-derived compounds in freshwater bodies can lead to changes in fish behaviour, hinder reproduction, and reduce survival rates (PetShun,2023).

The concentration of hormones was observed highest at the upper zone with a particular focus on Odha. The contamination of the river by hormones may be due to domestic sewage, Contamination may also come from livestock farm effluents and runoffs. A study conducted by Ana and Espino in 2020 revealed a comparable scenario, focusing on the presence and spread of hormones. However, the trace levels of hormones should not be neglected-for example, 17a-ethynylestradiol has the potential to trigger various endocrine dysfunction effects at exposure levels as low as 1 ng/L. This compound can Disrupt the endocrine and metabolism systems of aquatic organisms, especially in fish, which may cause changes in vitellogenin synthesis, feminization of males, inhibition of gonad development, hermaphroditism, and decrease in fish populations due to infertility (Adeel et al., 2017; Czarny et al., 2017).

The presence of bisphenol A (BPA) observed at the lower zone of the Godavari region contributes more BPA to the water, around Bhadrachalam, while the middle zone indicates its high dominance in the sediment around Mancherial. The phenolic xenoestrogens bisphenol A (BPA), octyl phenol (OP), and nonylphenol (NP) have wide industrial, household and agricultural applications including the use of these compounds in the production of plastics and detergents (Liu et al., 2020). Also, Bisphenol A (BPA) is a widely used material in modern manufacturing, including epoxy resins, polycarbonate plastics, and polyvinyl chloride plastics. It is commonly found in canned foods and household kitchenware due to its adhesive properties and is used in eyeglasses, optical devices, and medical equipment. These also reach the environment through domestic sewage, agricultural runoffs and industrial effluents (Esteban et al., 2014). Further, it can potentially sink in sediment and may result in exposure to benthic organisms (Staples et al., 2016). Most studies of BPA effects on wildlife focus on endocrine systems; PA is systemically toxic to various taxa, including daphnids (Alexander et al., 1988; Brennan et al., 2006; Hirano et al., 2004), mysids (Alexander et al., 1988; Hirano et al., 2004), and both freshwater (Pimephales promelas) and saltwater (*Menidia media*) fishes (Alexander et al., 1988). These Phenolic xenoestrogens have analogous chemical structures with estrogens that enable them to bind with estrogen receptor sites causing disruption of functions. This suggests that Absorption of BPA into the body can lead to the development of metabolic disorders, neurodevelopmental issues, immune toxicity, neurotoxicity, and interference with cellular pathways.

The presence of pyrethroids (Cypermethrin) was observed dominant in the upper zone around Odha. In sediment, pyrethroids have not been detected in the Godavari River. They are commonly employed for insect management, with applications in the household (such as Baygon spray and mosquito repellents) as well as in agricultural fields to control insects from the Coleoptera, Diptera, and Hemiptera Orders. Furthermore, they serve in the treatment of scabies and lice in humans (Thatheyus and Selvam 2013). Pyrethroids can come from municipal wastewater treatment plant discharges and urban stormwater runoff, as conventional treatment methods do not completely eliminate them, leading to their presence in the environment through plant effluents (Weston and Lydy 2010). So, the release of these compounds in water through the disposal of solid waste, industrial effluent, and untreated sewage can induce neurotoxic effects on fish by influencing their nervous system through the modulation of sodium channels (Ullah et al., 2019). Pyrethroids target voltage-gated channels such as calcium and chloride channels, along with the receptor for g-aminobutyric acid as their secondary targets (Soderlund, 2012). Exposure to synthetic pyrethroids can lead to a variety of behavioural abnormalities in fish, including reduced mobility, altered swimming patterns, an inability to maintain their position, diminished feeding, disrupted schooling behaviour, either hypo- or hyperexcitability, irregular or erratic swimming, increased opercula movements, sudden jerky motions, loss of balance, frequent surfacing, changes in vertical positioning, sinking to the bottom, increased activity, jumping, balance issues, immobility, and disturbances in migratory patterns. These effects were observed in different fish species such as *Tor putitora* (Ullah et al., 2014), *Labeo rohita* (Verma et al., 2016), and *Clarias batrachus* (Kumari et al., 2001). Pyrethroids, originally regarded as safe for humans and higher animals, are synthetic compounds derived from the natural pyrethrins found in the *Chrysanthemum cinerariaefolium* plant.

It was observed that HPCP were found to be more dominant in the middle zone around Kaleshwaram in the water sample and for sediment in the upper zone around copargaon highest domination was observed. The presence of HPCP particularly Triclosan was the most prevalent compound in water and sediment samples. Triclosan originates from various sources such as toothpaste, mouthwash, facial cleanser, aftershave, deodorant, body spray, lotion, cream, cosmetics, detergents, dishwashing liquids, Biofresh socks, undergarments, tops, bottoms, and Canopy kitchen towels. These PCPs are regularly introduced into the wastewater system as a result of their daily usage. Since many personal hygiene products are designed to be rinsed off, they ultimately find their way into the drain. It can have a unique impact on water bodies compared to other sources of endocrine-disrupting chemicals (EDCs).

The Godavari River, spanning 1,465 km, faces severe pollution from heavy metals (HMs) and endocrine-disrupting chemicals (EDCs), significantly impacting its water and sediment quality. Spatial mapping and interpolation have identified 390.87 km (26.7%) of the river as a heavy metal hotspot in water, while 300.86 km (20.5%) is contaminated in sediment, indicating long-term accumulation risks. Similarly, 102.34 km (7%) of the river is affected by EDCs in water, while 399.47 km (27.3%) is identified as an EDC hotspot in sediment, highlighting persistent contamination concerns. The primary pollution sources include industrial discharges, agricultural runoff, untreated sewage, urban expansion, and cultural practices. Heavy metals such as chromium, cadmium, mercury, lead, and zinc pose significant risks to aquatic life and human health due to their bio-accumulative nature, while EDCs like bisphenol A, phthalates, organochlorine pesticides, and synthetic pyrethroids disrupt hormonal functions in aquatic organisms, leading to reproductive and developmental disorders. The pollution intensity varies across different river zones, necessitating targeted mitigation measures. Urgent actions such as strengthening environmental policies, enhancing wastewater treatment, promoting sustainable agricultural practices, and increasing public awareness are crucial to restoring the river's ecological balance and protecting biodiversity.

Table 10.12 Heavy metals reported in other Indian rivers

River	Sample type	Heavy Metals	Reference
Barak	Water Sediment	Cu and Pb	Singh et al., (2016)
Ganga	Water	Cd, Co, Cr, Cu, Fe, Mn, Ni, Zn and Pb	Ajmal et al., (1987)
	Sediment	Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sn, and Zn	Ansari et al., (2000)
	Sediment	Cr, Mn, Fe, Co, Ni, Cu, Zn, Cd, and Pb	Singh et al., (2003)
	Water	Pb	Dutta et al., (2005)
Yamuna	Water	As	Jaiswal et al., (2022)
Cauvery	Water	Cd, Pb, Cu, Zn	Anbazhagan et al., (2021)
	Sediment	Cr, Cu, and Ni	Dhanakumar et al., (2015)
	Fish	Cr, Cu, Ni, and Pb	
	Water	As, Cd, Cu, Hg, Ni, and Pb	Myvizhi and Devi, (2020)
Periyar	Water	Al, Cd, Cr, Cu, Ni, and Pb	Nimisha and Sheeba (2014)
			Roshinebegam et al., (2015)
	Sediment	Cd, Cu, and Pb	Sreelakshmi and Chinnamma, (2018)
Mahanadi	Water	As and Hg	Kar et al., (2010)
	Water	Cd, Cr, Cu, Ni, and Pb	Sundaray et al., (2012)
	Sediment	Cd, Cr, Cu, Ni, and Pb	Sundaray et al., (2014)
	Water	As, Cd, Cr, Hg, Ni, and Pb	Hussain et al., (2020)
Narmada	Water	As, Cd, Cr, Cu, Ni, and Pb	Sharma and Subramanian, (2010)
	Sediment	Al, As, Cd, Cr, Cu, Ni, and Pb	
	Water	As, Cd, Cr, Cu, Ni, and Pb	Arif et al., (2014)

Table 10.13: Endocrine Disrupting Compounds reported in various Indian river

River	Sample Type	EDCs	Reference
Godavari	Water	Cu and Pb	Bhalla and Waykar, (2013)
	Water	Cd, Cr, Hg, and Pb	Patil and Kaushik, (2016)
	Sediment		
	Sediment	Cd, Cu, Ni, and Pb	Prasad et al., (2019)
	Water	As, Cd, Cr, Cu, Ni, Pb Zn, and Fe,	Hussain et al., 2017)
	Water	Fe, Cu, Cr, Pb, Cd, Zn, F	Ghorade et al., (2014)
	Sediment	Ni, Fe, Cr, Cu, Zn, Co, Pb, Cd & As	Babu et al., (2023)
Gomti	Water	-	-
	Sediment	DMP, DEP, DBP, DEHP, DOP	Srivastava et al., (2010)
Ganga	Water	DMP, DEP, DBP, BBP, DEHP, DOP, Caffeine, BPA	Chakraborty et al., (2021)
	Sediment	-	-
Kaveri	Water	DMP, DEP, DBP, BBP, DEHP, DOP	Selvaraj et al., (2015)
	Sediment	DMP, DEP, DBP, BBP, DEHP, DOP	
Brahmaputra	Water	a-HCH, b-HCH, g-HCH, d-HCH, SHCHs, p, p'-DDD, o, p'-DDT, p, p'-DDT, SDDTs, Heptachlor, Aldrin, Dieldrin, SAldrin, a- Endosulfan, b-Endosulfan, SEndosulfan, SOCPs	
	Sediment	-	
Tapi	Water	SDDTs, a-Endosulfan, b-Endosulfan, Chlorpyrifos, Methyl Parathion	Sarker et al., (2021)
	Sediment	SDDTs, a-Endosulfan, b-Endosulfan, Chlorpyrifos, Methyl parathion,	
Hooghly	Water	a-HCH, b-HCH, g-HCH, d-HCH, SHCHs, o,p'-DDT, p,p'-DDT, SDDTs, Heptachlor, Aldrin, Dieldrin, SAldrin, b-Endosulfan, bEndosulfan, SOCPs,	
	Sediment	a-HCH, b-HCH, g-HCH, d-HCH, e-HCH, o,p'-DDD, p,p'-DDD, o,p'- DDE, o,p'-DDE, p,p'-DDE, o,p'-DDT, p,p'-DDT, SDDTs,	
Periyar	Water	estriol, estrone, 17 b estradiol, progesterone, and hydroxy progesterone	Unnikrishan et al., (2024)
Yamuna	Water	Caffeine, Trimethoprim, Ciprofloxacin, Sulfamethoxazole, Enrofloxacin, Testosterone, Progesterone, Estrone, Diclofenac, Naproxen, Ketoprofen, Carbamazepine, Atenolo, Triclosan, Gemfibrozil, 2-Hydroxybenzothiazole	Biswas and Vellanki, (2021)
Ganga	Water	Acetaminophen, triclosan, diethyl-meta-toluamide (DEET), tetracycline, caffeine, Ibuprofen, ketoprofen, acetaminophen, ciprofloxacin, tetracycline, ofloxacin, salicylic acid	Singh and Suthar, (2021)
Bharula	Water	DMP, DEP, DEHP, DOP	Saptadeepa Roy and Kalita, (2011)

References

Aarab N, Lemaire-Gony S, Unruh E, Hansen P, Larsen BK, Andersen O and Narbonne J (2006) Preliminary study of responses in mussel (Mytilus edilus) exposed to bisphenol A, diallyl phthalate and tetrabromodiphenyl ether. Aquatic Toxicology 78, S86-S92.

Adeel M, Song X, Wang Y, Francis D and Yang Y (2017) Environmental impact of estrogens on human, animal and plant life: A critical review. Environment international 99, 107-119.

Ajmal M, Khan MA and Nomani AA (1987) Monitoring of heavy metals in the water and sediments of the Ganga River, India. Water science and technology 19(9), 107-117.

Anbazhagan V, Rajendran R, Arumugam G and Ganeshan A (2021) Identification of heavy metal pollution source due to idol immersion activity across the Cauvery river basin, Tamil Nadu, South India. Current Science 120(1), 200.

Ansari A, Singh I and Tobschall H (2000) Importance of geomorphology and sedimentation processes for metal dispersion in sediments and soils of the Ganga Plain: identification of geochemical domains. Chemical Geology 162(3-4), 245-266.

Ansari A, Singh I and Tobschall H (2000) Importance of geomorphology and sedimentation processes for metal dispersion in sediments and soils of the Ganga Plain: identification of geochemical domains. Chemical Geology 162(3-4), 245-266.

Arambourou H, Planelló R, Llorente L, Fuertes I, Barata C, Delorme N, Noury P, Herrero Ó, Villeneuve A and Bonnineau C (2019) Chironomus riparius exposure to field-collected contaminated sediments: from subcellular effect to whole-organism response. Science of the Total Environment 671, 874-882.

Archna Akhand AA, Pratibha Akhand PA, Shukla A and Sharad Shrivastava SS (2012) Accumulation of zinc in fresh water food fishes of Chambal River India.

Arif MA, Hussain J and Hussain I (2014) Occurrence of Trace and Toxic metals in River Narmada. In.

BABU K, SUDHAKAR G and NIRMALA PV (2023) Heavy Metal Analysis in Agricultural Soils in Godavari River Basin of Rajahmundry Region, East Godavari District, Andhra Pradesh, India. Current Agriculture Research Journal 11(2).

Barman B, Kumar B and Sarma AK (2019a) Dynamic characterization of the migration of a mining pit in an alluvial channel. International journal of sediment research 34(2), 155-165.

Barman B, Kumar B and Sarma AK (2019b) Impact of sand mining on alluvial channel flow characteristics. Ecological Engineering 135, 36-44.

Bere T, Chia MA and Tundisi JG (2012) Effects of Cr III and Pb on the bioaccumulation and toxicity of Cd in tropical periphyton communities: Implications of pulsed metal exposures. Environmental pollution 163, 184-191.

Berman T, Hochner-Celnikier D, Calafat AM, Needham LL, Amitai Y, Wormser U and Richter E (2009) Phthalate exposure among pregnant women in Jerusalem, Israel: results of a pilot study. Environment international 35(2), 353-357.

Besada V, Fumega J and Vaamonde A (2002) Temporal trends of Cd, Cu, Hg, Pb and Zn in mussel (Mytilus galloprovincialis) from the Spanish North-atlantic coast 1991-1999. Science of the Total Environment 288(3), 239-253.

Bhalla R and Sekhon B (2010) Seasonal physico-chemical characteristics assessment and primary production in the planktonic community of Godavari River water, Nashik (Maharashtra). Environment Conservation Journal 11(1&2), 41-45.

Bhalla R and Waykar B (2013) Monitoring of water quality and pollution status of Godavari River in and around Nashik region, Maharashtra. Nature Environment and Pollution Technology 12(1), 125.

Bhattacharya RK, Das Chatterjee N and Dolui G (2019) Consequences of sand mining on water quality and instream biota in alluvial stream: a case-specific study in South Bengal River, India. Sustainable Water Resources Management 5, 1815-1832.

Bhattacharya S, Bera A, Dutta A and Ghosh UC (2014) Effects of idol immersion on the water quality parameters of Indian water bodies: Environmental health perspectives. International Letters of Chemistry, Physics and Astronomy 20(2), 234--263.

Biswas P and Vellanki BP (2021) Occurrence of emerging contaminants in highly anthropogenically influenced river Yamuna in India. Science of the Total Environment 782, 146741.

Chakraborty P, Shappell NW, Mukhopadhyay M, Onanong S, Rex KR and Snow D (2021) Surveillance of plasticizers, bisphenol A, steroids and caffeine in surface water of River Ganga and Sundarban wetland along the Bay of Bengal: occurrence, sources, estrogenicity screening and ecotoxicological risk assessment. Water Research 190, 116668.

Chang-Hong C, Hong-Ling M, Yi-Qin D, Juan F, Yu-Kun J and Zhi-Xun G (2021) Oxidative stress, cell cycle arrest, DNA damage and apoptosis in the mud crab (Scylla paramamosain) induced by cadmium exposure. Chemosphere 263, 128277. https://doi.org/https://doi.org/10.1016/j.chemosphere.2020.128277.

Czarny K, Szczukocki D, Krawczyk B, Zieli?ski M, Mi?ko? E and Gadza?a-Kopciuch R (2017) The impact of estrogens on aquatic organisms and methods for their determination. Critical reviews in environmental science and technology 47(11), 909-963.

Dhanakumar S, Solaraj G and Mohanraj R (2015) Heavy metal partitioning in sediments and bioaccumulation in commercial fish species of three major reservoirs of river Cauvery delta region, India. Ecotoxicology and environmental safety 113, 145-151. https://doi.org/10.1016/j.ecoenv.2014.11.032.

dos Santos JA, Quadra GR, Almeida RM, Sorango L, Lobo H, Rocha VN, Bialetzki A, Reis JL, Roland F and Barros N (2022) Sublethal effects of environmental concentrations of caffeine on a neotropical freshwater fish. Ecotoxicology 31(1), 161-167. https://doi.org/10.1007/s10646-021-02498-z.

Dutta S, Kole R, Ghosh S, Nath D and Vass K (2005) Impact assessment of lead on water quality of river Ganga in West Bengal, India. Bulletin of environmental contamination and toxicology 75(5), 1012-1019.

Esteban S, Gorga M, González-Alonso S, Petrovic M, Barceló D and Valcárcel Y (2014) Monitoring endocrine disrupting compounds and estrogenic activity in tap water from Central Spain. Environmental Science and Pollution Research 21, 9297-9310.

Fent K, Weston AA and Caminada D (2006) Ecotoxicology of human pharmaceuticals. Aquatic Toxicology 76(2), 122-159.

Flippin JL, Huggett D and Foran CM (2007) Changes in the timing of reproduction following chronic exposure to ibuprofen in Japanese medaka, Oryzias latipes. Aquatic Toxicology 81(1), 73-78.

Froehner S, Piccioni W, Machado KS and Aisse MM (2011) Removal capacity of caffeine, hormones, and bisphenol by aerobic and anaerobic sewage treatment. Water, Air, & Soil Pollution 216, 463-471.

Gaur VK, Gupta SK, Pandey S, Gopal K and Misra V (2005) Distribution of heavy metals in sediment and water of river Gomti. Environmental monitoring and assessment 102, 419-433.

Georgaki M-N and Charalambous M (2023) Toxic chromium in water and the effects on the human body: a systematic review. Journal of water and health 21(2), 205-223.

Ghorade I, Lamture S and Patil S (2014) Assessment of heavy metal content in Godavari river water. International Journal of Research in Applied, Natural and Social Sciences, 2(6), 23-26.

Gilbert R (1984) Caffeine consumption. Progress in clinical and biological research 158, 185-213.

Gonzalez-Rey M and Bebianno MJ (2012) Does non-steroidal anti-inflammatory (NSAID) ibuprofen induce antioxidant stress and endocrine disruption in mussel Mytilus galloprovincialis? Environmental Toxicology and Pharmacology 33(2), 361-371.

Hinton RH, Mitchell FE, Mann A, Chescoe D, Price SC, Nunn A, Grasso P and Bridges JW (1986) Effects of phthalic acid esters on the liver and thyroid. Environmental health perspectives 70, 195-210.

Hossini H, Shafie B, Niri AD, Nazari M, Esfahlan AJ, Ahmadpour M, Nazmara Z, Ahmadimanesh M, Makhdoumi P, Mirzaei N and Hoseinzadeh E (2022) A comprehensive review on human health effects of chromium: insights on induced toxicity. Environmental Science and Pollution Research 29(47), 70686-70705. https://doi.org/10.1007/s11356-022-22705-6.

Hussain J, Dubey A, Hussain I, Arif M and Shankar A (2020) Surface water quality assessment with reference to trace metals in River Mahanadi and its tributaries, India. Applied Water Science 10(8).

Hussain J, Husain I, Arif M and Gupta N (2017) Studies on heavy metal contamination in Godavari river basin. Applied Water Science 7(8), 4539-4548. https://doi.org/10.1007/s13201-017-0607-4.

INDIA-WRIS (2014) Godavari Basin Report Ministry of Water Resources, Government of India Version 2. https://indiawrisgovin

Jaiswal M, Gupta SK, Chabukdhara M, Nasr M, Nema AK, Hussain J and Malik T (2022) Heavy metal contamination in the complete stretch of Yamuna river: A fuzzy logic approach for comprehensive health risk assessment. PLoS One 17(8), e0272562. https://doi.org/10.1371/journal.pone.0272562.

Jani K, Dhotre D, Bandal J, Shouche Y, Suryavanshi M, Rale V and Sharma A (2018) World's largest mass bathing event influences the bacterial communities of Godavari, a holy river of India. Microbial ecology 76, 706-718.

Kar P, Pani K, Pattanayak S and Sahu S (2010) Seasonal variation in physico-chemical and microbiological parameters of Mahanadi river water in and around Hirakud, Orissa (India). The Ecoscan 4(4), 263-271.

Kasonga TK, Coetzee MA, Kamika I, Ngole-Jeme VM and Momba MNB (2021) Endocrine-disruptive chemicals as contaminants of emerging concern in wastewater and surface water: A review. Journal of environmental management 277, 111485.

Kondolf G and Swanson M (1993) Channel adjustments to reservoir construction and gravel extraction along Stony Creek, California. Environmental Geology 21(4), 256-269.

Kondolf GM (1994) Geomorphic and environmental effects of instream gravel mining. Landscape and Urban planning 28(2-3), 225-243.

Korekar G, Kumar A and Ugale C (2020) Occurrence, fate, persistence and remediation of caffeine: a review. Environmental Science and Pollution Research 27, 34715-34733.

Kulkarni J and Shrivastava V (2000) Physical and chemical investigation for the assessment of pollution in and around industrial area. Indian Journal of Environmental Protection 20(4), 252-256.

Kumari A, Sinha R and Gopal K (2001) Organochlorine contamination in the fish of the River Ganges, India. Aquatic Ecosystem Health & Management 4(4), 505-510.

Li WC and Tse HF (2015) Health risk and significance of mercury in the environment. Environmental Science and Pollution Research 22(1), 192-201. https://doi.org/10.1007/s11356-014-3544-x.

Liu B, Li T, Wang W, Sagis LM, Yuan Q, Lei X, Cohen Stuart MA, Li D, Bao C and Bai J (2020) Corncob cellulose nanosphere as an eco-friendly detergent. Nature Sustainability 3(6), 448-458.

Marchlewicz A, Domaradzka D, Guzik U and Wojcieszy?ska D (2016) Bacillus thuringiensis B1 (2015b) is a gram-positive bacteria able to degrade naproxen and ibuprofen. Water, Air, & Soil Pollution 227, 1-8.

Mergler D (2021) Ecosystem approaches to mercury and human health: A way toward the future. Ambio 50(3), 527-531. https://doi.org/10.1007/s13280-020-01455-0.

Mohinuzzaman M, Saadat A, Mostofa K, Islam S, Hossain S and Tareq S (2018) Health risk assessment of chromium-accumulated fish and vegetables at Gulshan Lake of Bangladesh: a case study. Pollution 4(3), 459-469.

Moore M, Greenway S, Farris J and Guerra B (2008) Assessing caffeine as an emerging environmental concern using conventional approaches. Archives of environmental contamination and toxicology 54, 31-35.

Myvizhi P and Devi PA (2020) Heavy metal contamination in water of the River Cauvery-a case study of Erode, Salem and Namakkal districts, Tamil Nadu. Journal of Himalayan Ecology and Sustainable Development,15, 1-18.

Nisha J, Jeya SRR and Chandran R (2016) Acute effect of chromium toxicity on the behavioral response of zebra fish Danio rerio. International journal of plant, animal and environmental sciences 6(2), 6-14.

NWCM C (2014-2015) Environmental Status Report Nanded Waghala City.

PetShun. (2023). The effects of coffee spills on freshwater fish: Can they survive? PetShun. https://www.petshun.com/the-effects-of-coffee spills-on-freshwater-fish-can-they-survive

Padmalal D, Maya K, Padmalal D and Maya K (2014) River sand mining and mining methods. Sand Mining: Environmental Impacts and Selected Case Studies, 23-30.

Palo AK and Choudhury RC (2006) Modulation of methotrexate-induced cytogenotoxicity in mouse spermatogonia and its transmission in the male germline by caffeine. Environmental Toxicology and Pharmacology 21(3), 254-259.

Patil SS and Kaushik G (2016) Heavy metal assessment in water and sediments at Jaikwadi dam (Godavari river) Maharashtra, India. International Journal of Environment 5(2), 75-88.

Poulin R, Pakalnis R and Sinding K (1994) Aggregate resources: production and environmental constraints. Environmental Geology 23, 221-227.

Prasad H, Bhanu Murty P, Sanyasi Rao M and Duvvuru R (2019) A Study on Assessment of Pollution in Godavari Estuary East Coast of India by Using Trace Metals Concentration in the Sediments. In Proceedings of International Conference on Remote Sensing for Disaster Management, 439-453.

Ray P, Malla G, Johnson J and Sivakumar K (2022) An overview of the fish diversity and their threats in the Gowthami-Godavari Estuary in Andhra Pradesh, India. Journal of Threatened Taxa 14(8), 21588-21604.

Rinaldi M, Wy?ga B and Surian N (2005) Sediment mining in alluvial channels: physical effects and management perspectives. River Research and Applications 21(7), 805-828.

Roshinebegam K, Selvakumar S and Sundararajan S (2015) Assessing of Water Quality Pollution Indices for Heavy Metal Contamination of Periyar River, Tamil Nadu, South India. Chem. Sci. Rev. Lett. 4(13), 153-163.

Rudolph E, Färbinger A and König J (2012) Determination of the caffeine contents of various food items within the Austrian market and validation of a caffeine assessment tool (CAT). Food Additives & Contaminants: Part A 29(12), 1849-1860.

Sah R, Khanduri M, Chaudhary P, Paul KT, Gururani S, Banwala K, Paul C, Jose MA, Bora S, Ramachandran A, Badola R, and Hussain SA (2024) Dietary exposure of potentially toxic elements to freshwater mammals in the Ganga river basin, India. Environmental Pollution, 351, 123928.

Sandecki M (1989) Aggregate mining in river systems. California Geology 42(4), 88-94.

Saptadeepa Roy SR and Kalita JC (2011) Determination of endocrine disrupting compounds in water bodies around Guwahati city, Assam, India through gas chromatography/mass spectrometry.

Sarker S, Akbor MA, Nahar A, Hasan M, Islam ARMT and Siddique MAB (2021) Level of pesticides contamination in the major river systems: A review on South Asian countries perspective. Heliyon 7(6).

Selvaraj KK, Sundaramoorthy G, Ravichandran PK, Girijan GK, Sampath S and Ramaswamy BR (2015) Phthalate esters in water and sediments of the Kaveri River, India: environmental levels and ecotoxicological evaluations. Environmental Geochemistry and Health 37, 83-96.

Shackley M (2001) Managing Sacred Sites; service provision and visitor experience. Continuum.

Shaikh P, Deore G, Pathare A, Pathare D and Pawar R (2021) Assessment of Godavari River Water Quality of Nanded City, Maharashtra, India. In: Techno-Societal 2020: Proceedings of the 3rd International Conference on Advanced Technologies for Societal Applications-Volume 1. Springer.

Sharma SK and Subramanian V (2010) Source and distribution of trace metals and nutrients in Narmada and Tapti river basins, India. Environmental Earth Sciences 61(7), 1337-1352. https://doi.org/10.1007/s12665-010-0452-3.

Singh M, Müller G and Singh IB (2003) Geogenic distribution and baseline concentration of heavy metals in sediments of the Ganges River, India. Journal of Geochemical Exploration 80(1), 1-17.

Singh P, Dey M and Ramanujam SN (2016) Bioaccumulation of heavy metals in anuran tadpoles: A study in Barak Valley, Assam. International Journal of Aquatic Biology 4(3), 171-178.

Singh V and Suthar S (2021) Occurrence, seasonal variations, and ecological risk of pharmaceuticals and personal care products in River Ganges at two holy cities of India. Chemosphere 268, 129331.

Sreelakshmi C and Chinnamma M (2018) Quality Assessment of Sediments in Bharathapuzha with Special Reference to Phosphate Fractionation and Metallic Contaminatio. Int. J. Adv. Info. Eng. Technol 5(4).

Srivastava A, Sharma VP, Tripathi R, Kumar R, Patel DK and Mathur PK (2010) Occurrence of phthalic acid esters in Gomti River Sediment, India. Environmental monitoring and assessment 169, 397-406.

Staples C, Mihaich E, Ortego L, Caspers N, Kle?ka G, Woelz J and Hentges S (2016) Characterizing the effects of bisphenol A on sediment?dwelling benthic organisms. Environmental Toxicology and Chemistry 35(3), 652-659.

Staples CA, Peterson DR, Parkerton TF and Adams WJ (1997) The environmental fate of phthalate esters: a literature review. Chemosphere 35(4), 667-749.

Sundaray SK, Nayak BB, Kanungo TK and Bhatta D (2012) Dynamics and quantification of dissolved heavy metals in the Mahanadi river estuarine system, India. Environmental monitoring and assessment 184, 1157-1179.

Sundaray SK, Nayak BB, Lee B-G and Bhatta D (2014) Spatio-temporal dynamics of heavy metals in sediments of the river estuarine system: Mahanadi basin (India). Environmental Earth Sciences 71, 1893-1909.

Sunilkumar R (2002) Impact of sand mining on benthic fauna: a case study from Achankovil river-an overview. Catholicate College, Pathanamthitta district, Kerala 38.

Thatheyus A and Selvam AG (2013) Synthetic pyrethroids: toxicity and biodegradation Appl Ecol Environ Sci 1(3), 33-36.

Tripathy B, Shanker K and Choudhury B (2003) Important nesting habitats of olive ridley turtles Lepidochelys olivacea along the Andhra Pradesh coast of eastern India. Oryx 37.

Ullah R, Zuberi A, Ullah S, Ullah I and Dawar FU (2014) Cypermethrin induced behavioral and biochemical changes in mahseer, Tor putitora. The Journal of toxicological sciences 39(6), 829-836.

Unnikrishan A, Khalid NK, Rayaroth MP, Thomas S, Nazim A, Aravindakumar CT and Aravind UK (2024) Occurrence and distribution of steroid hormones (estrogen) and other contaminants of emerging concern in a south indian water body. Chemosphere 351, 141124.

Verma R, Singh AK and Jaiswal K (2016) Preliminary study on diminution level of RNA/DNA ratio in tissue of Labeo rohita by exposure to some endocrine disrupting compounds (EDCs). Aceh Journal of Animal Science 1(1), 16-20.

Verma S, Sahu RT, Singh H, Prasad A and Verma M (2022) A study of Environmental and Ecological impacts due to Construction and Operation of Tehri-Polavaram Dam. In: IOP Conference Series: Earth and Environmental Science. IOP Publishing.

Wang F, Chen L, Jiao J, Zhang L, Ji Y, Bai Z, Zhang L and Sun Z (2012) Pollution characteristics of phthalate esters derived from household dust and exposure assessment. China Environmental Science 32(5), 780-786.

Weeks J, Sims I, Lawson C and Harrison D (2003) River mining: assessment of the ecological effects of river mining in the Rio Minho and Yallahs rivers, Jamaica.

Weston DP and Lydy MJ (2010) Urban and agricultural sources of pyrethroid insecticides to the Sacramento-San Joaquin Delta of California. Environmental science & technology, 44(5), 1833-1840. https://doi.org/10.1021/es9035573.

Yixia C, Shihao Z, Kunzheng C, Fei H, Bogui P and Wei W (2020) Cd accumulation, biomass and yield of rice are varied with silicon application at different growth phases under high concentration cadmium-contaminated soil. Chemosphere 242, 125128. https://doi.org/https://doi.org/10.1016/j.chemosphere.2019.125128.

Zamani-Ahmadmahmoodi R, Malekabadi MB, Rahimi R and Johari SA (2020) Aquatic pollution caused by mercury, lead, and cadmium affects cell growth and pigment content of marine microalga, Nannochloropsis oculata. Environmental monitoring and assessment 192(6), 330. https://doi.org/10.1007/s10661-020-8222-5.

Zhang Y, Jiao Y, Li Z, Tao Y and Yang Y (2021) Hazards of phthalates (PAEs) exposure: A review of aquatic animal toxicology studies. Science of the Total Environment 771, 145418.

Zou W, Tolonen KT, Zhu G, Qin B, Zhang Y, Cao Z, Peng K, Cai Y and Gong Z (2019) Catastrophic effects of sand mining on macroinvertebrates in a large shallow lake with implications for management. Science of the Total Environment 695, 133706.

11

GENETIC DIVERSITY AND GENE FLOW

11

GENETIC DIVERSITY AND GENE FLOW

Abstract

The study aimed to assess the impact of dams or other water control structures on select fish species in the Godavari River. Genetic diversity was assessed for Wallago attu, Puntius sophore, Devario aequipinnatus, and Garra mullya using mitochondrial loci and microsatellite markers. The haplotype diversities values for Wallago attu, Puntius sophore, Devario aequipinnatus and Garra mullya were 0.64 (±0.04), 0.76 (±0.08), 0.82 (±0.07) and 0.34 (±0.17), respectively. The observed heterozygosity value based on microsatellite analysis for W. attu was 0.53 (±0.04), indicating a moderate level of genetic diversity. Genetic differentiation was measured low (Fst =0.03 ±0.01). Asymmetrical gene flow was found across the populations of W. attu. In this, low gene flow rate was observed between upper and middle zone populations. This could be due to poor water quality and highly industrialized areas near to the river in upper zone, restricting migrations for the aquatic species, particularly fishes.

11.1 Introduction

The Godavari River is the second largest east-flowing river in India (Das et al., 2021), and is fragmented by numerous barriers, including some major dams such as Jayakwadi Dam, Gangapur Dam, Dummugudem Barrage, Vishnupuri Barrage, Sriram Sagar Project, Polavaram Project, Kaleshwaram Lift Irrigation Project (India-WRIS). These barriers can harm aquatic species by disrupting their natural habitats, making it harder for them to move between different areas and affecting their growth and survival stages (Rahel, 2013). As a result species may face smaller populations, less genetic diversity, more inbreeding, and even local extinction.

In present study, to address river fragmentation and anthropogenic pressures, assessment of genetic diversity and gene flow was estimated in fishes of Godavari River viz., Asian silurid catfish (*Wallago attu* Bloch and Schneider, 1801), Pool barb (*Puntius sophore* Hamilton-Buchanan, 1822), Giant danio (*Devario aquepinnatus* McClelland, 1839), and Stone sucker fish (*Garra mullya* Sykes, 1839). These species were selected for genetic analysis based on their distribution in the entire Godavari River except *G. mullya* which is found in cleaned and optimal oxygenated water with a rocky substratum. Additionally, they were also selected due to their high risk

from human activities and the significant demand in the aquarium trade (*P. sophore* and *D. aquepinnatus*). Whereas, *W. attu* is an economically important species and has a high demand for consumption. Currently, *W. attu* has been categorized as vulnerable, with a rapidly decreasing population in the IUCN red list.

The present study was conducted to understand the genetic variability and gene flow in the selected fish species in the Godavari River, which might have been affected due to river fragmentation.

11.2 Methods of Assessment

11.2.1 Sampling sites

A total of 142 samples of fishes were collected, which included 76 samples of *W. attu*, 25 samples of *P. sophore*, 29 samples of *D. aequipinnatus*, and 12 sample of *G. mullya*. For *W. attu*, samples were collected from three populations, viz., 24 samples from GUZ, 25 samples from GMZ, and 27 samples from GLZ. Whereas, the samples of *P. sophore, G. mullya*, and *D. aequipinnatus* were collected from the GUZ. Each fish samples were collected using gill nets (20 to 40 mm) or 20 mm cast nets with the help of local fishermen. Additionally, fish samples were also collected from the local fish market located adjacent to the Godavari River. Tissue samples of either pectoral or caudal fins were collected using a sterile stainless scissor and stored in a sterile tube filled with absolute high-grade ethanol. All the collected tissue samples were preserved at low temperatures (4 °C) for further analysis in the laboratory (Table 11.1 and Figure 11.1).

Table 11.1 Details of sampling location of selected fish species from the Godavari River.

Species	Sampling locations	River zone	Population code	N
W. attu	Jyakwadi to Sriram Sagar Dam	Upper	GUZ	24
	Sriram Sagar Dam to Lakshmi Barrage	Middle	GMZ	25
	Lakshmi Barrage to Coastal End	Lower	GLZ	27
P. sophore	River source to Nandur Madhmeshwar Dam	Upper	GUZ	03
	Nandur Madhmeshwar to Jyakwadi Dam	Upper	GUZ	22
D. aequipinnatus	River source to Nandur Madhmeshwar Dam	Upper	GUZ	26
	Nandur Madhmeshwar to Jyakwadi Dam	Upper	GUZ	03
G. mullya	River source to Sriram Sagar Dam	Upper	GUZ	12
	Grand Total			142

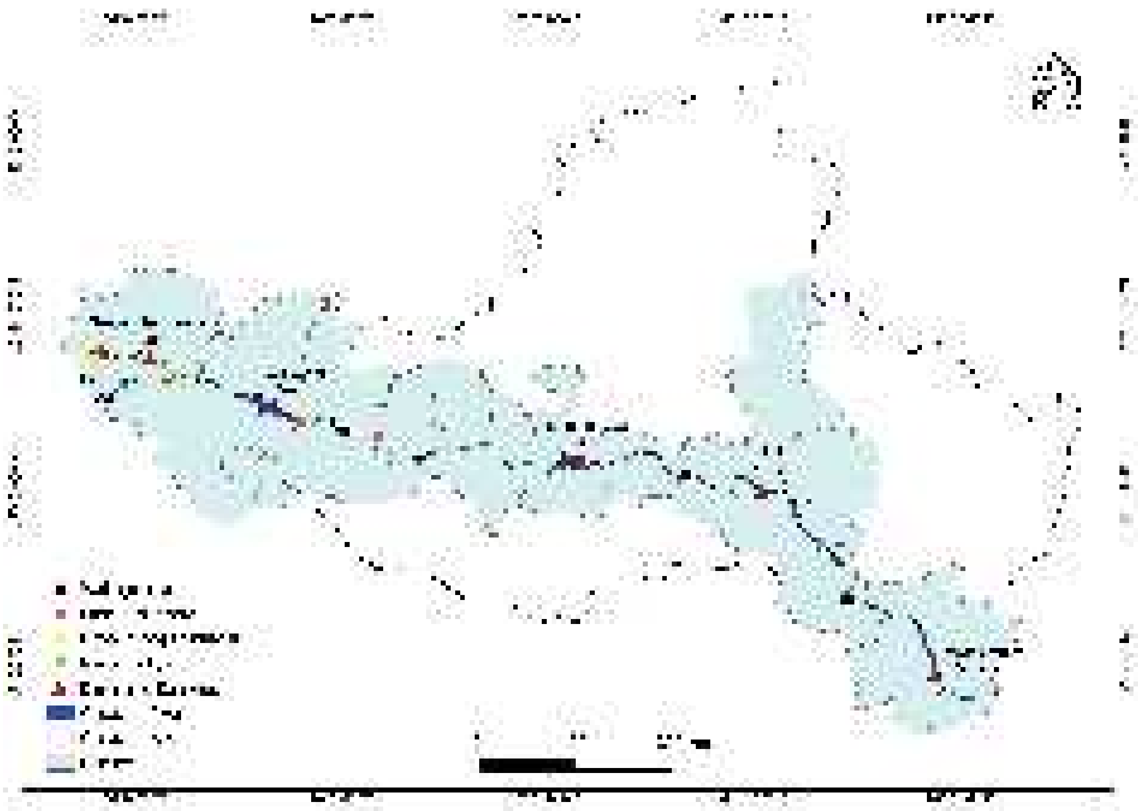


Figure 11.1 Map showing sampling locations of fishes in Godavari River

11.2.2 Genomic DNA extraction

Genomic DNA was extracted from the biological samples using a DNeasy tissue and blood kit (Qiagen, Hilden, Germany). The quality and quantity of the eluted DNA was assessed on 0.8 % agarose gel eletrophoresis and a fluorometer machine (Promega, Madison, US).

11.2.3 Primer selection

11.2.3.1 Mitochondrial primer

The analyses of genetic diversity in selected species was carried out using varied sets of primer pairs. For *W. attu*, the Cytochrome b gene (Cyt b~500 bp) was amplified with primers L14724 and H15915 (Xiao et al., 2001). Cytochrome oxidase I (COI~600 bp) gene in *P. sophore, D. aequipinnatus* and *G. mullya,* was selected to analyze the genetic diversity (Ward et al., 2005).

11.2.3.2 Microsatellite primer

Microsatellite markers (Short Tandem Repeats: STRs) relevant to fish were searched in published literature. A total of 13 primer pairs for *W. attu* were selected based on criteria such as allele size range (100 to 250 bp), number of alleles (>5), PIC values (>0.5) and observed heterozygosity. Each forward primer was attached with 5'- end adapter sequences of either with M13 sequence (5'-TGTAAAACGACGGCCAGT-3) or AP2 sequence (5'-CAGGAAACAGCTATGACC-3).

All synthesized STR primer pairs were initially tested for amplification and polymorphism using one random sample from each of the three populations of *W. attu*. The optimum temperature was assessed by gradient temperature ranging between 50 and 60 °C. For *W. attu*, 13 primer pairs (WAM16, WAM17, WAM21, WAM23, WAM24, WAM27, WAM8, WAM28, WAM29, WAM30, WAM32, WAM33, and WAM39) were amplified successfully and polymorphic (Singh et al., 2013).

11.2.4 DNA amplification, sequencing and fragment analysis

DNA amplification of mitochondrial genes was carried out using a thermal cycler (Applied Biosystems, USA) using optimized conditions in 10 µl PCR reaction mixture containing 1 µl template DNA, 5 µl Qiagen Master mix (QIAGEN Multiplex PCR Kit, Germany), 1 µl of BSA (Hi-media), 0.2 µl of 0.25 nmol forward and 0.2 µl of 0.25 nmol reverse primers (IDT, India), and 2.6 µl distilled water. This reaction mixture was initially denatured (96 °c for 15 minutes), 35 cycles of denaturation (94°C for 40 seconds), annealing (55°C for 45 seconds), and extension (72°C for 1 minute 30 seconds), followed by a final extension of 72 °C for 30 min. The amplified PCR products were subjected to further sequencing.

Sanger sequencing method was used to determine the nucleotide base pair sequence of the mitochondrial DNA template using Big dye terminator v3.1 (Thermo fisher Scientific, USA). The sequences were then analysed with a Bio-analyser ABI 3500XL machine (Applied Biosystems, US).

Genotyping of the microsatellite DNA was performed using a primer mixture, reagents, and DNA templates in the total volume of 7 Sl comprised of 1 mL template DNA, 3 mL multiplex master mix buffer, 1 mL Bovine Serum Albumin, 0.2 mL of primer mixture (1 µl 5'-end adapter forward primer, 4 µl non adapter reverse primer, 4 µl of either M13 and AP2 primer and 11 µl RNase free water), and rest RNase free water. DNA amplification was carried out by using PCR thermal cycle under the touchdown conditions; initial denaturation at 95 °C for 15 min, followed by 8 cycles of denaturation at 95 °C for 30 sec., annealing at 60 °C for 90 sec. and extension at 72 °C for 30 sec, again followed by 20 stages of 1 cycle of denaturation at 95 °C for 30 sec, annealing at 60-50 °C (with a -0.5 °C drop each cycle) for 90 sec, and extension at 72 °C for 30 sec which followed by 12 cycles of denaturation at 95 °C for 30 sec, annealing at 50 °C for 90 sec, and extension at 72 °C for 30 sec with final extension of 60 °C for 30 min. The amplified PCR product was visualized on UV illuminator and then subjected to fragment analysis. For fragment analysis, 0.11 ml LIZ Gene scanner (Applied Biosystems, USA) and 8.89 ml Hi Di formamide (Thermo Fisher Scientific, USA) were added to each amplicon and subjected to analyse in ABI 3500 XL automated Bioanalyzer ABI machine.

11.2.6 Data analysis

The mitochondrial sequence data generated for selected fish species were manually examined and edited using CLUSTAL W function of Bio-edit v4.1 (Hall, 1999). DnaSP v5.2 (Librado and Rozas, 2009) was used to determine the nucleotide diversity (p), number of haplotype (h), haplotype diversity (Hd) and polymorphism sites (s) from mitochondrial Cytb and COI DNA sequences. Further, a median-joining network was generated to visualize the spatial distribution of the haplotypes using the PopART v1.7 (Leigh et al., 2015).

Microsatellite data was scored using the program GeneMarker v2.7.4 (SoftGenetics, USA). Genetic diversity parameters viz., the number of effective alleles (Ne), alleles per locus (Na), observed (Ho), and expected heterozygosity (He) were estimated using the GenAlEx v6.5 program (Peakall and Smouse 2006). The estimation of contemporary migration rates within and among populations was analyzed in BayesAss v4.2.0 program. Multiple independent runs were performed to ensure consistency and convergence of the result.

11.3 Population genetics of *Wallago attu*

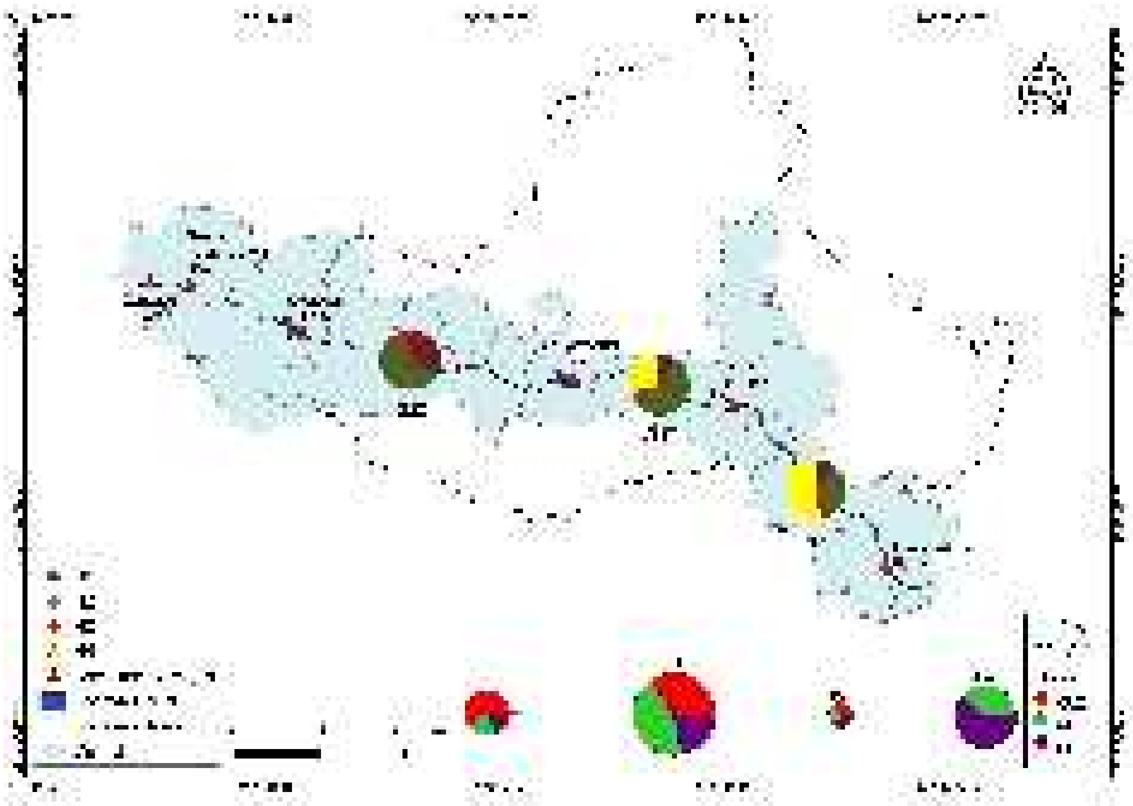
11.3.1 Mitochondrial genetic diversity

The aligned length of the Cytb gene in *W. attu* was 507 bp. A total of six substitution sites was detected at nucleotide positions 162, 343, 346, 461, 485, and 495 with reference to the partial mitochondrial Cytb gene (Gene bank Accession No.: OR943873.1). A total of four haplotypes (H1-H4) were identified.

Overall, the haplotype diversity (Hd) and nucleotide diversity (p) were 0.643 (±0.04) and 0.00499 (±0.00044), respectively. Among the populations, the GLZ population exhibited the highest genetic diversity, with Hd = 0.633 and p = 0.00573 followed by the GMZ population, which displayed comparatively lower genetic diversity (Hd = 0.590 and p = 0.00491). The GUZ population showed the least genetic diversity (Hd = 0.542 and p = 0.00143).

The Haplotype network revealed a simple linear network (Figure 11.2). The most common haplotype was H2, present in the 32 individuals (50.7%) followed by H4 (28.5%), H1 (15.8%) and H3 (0.04%). Haplotypes H1, H2 and H3 were present in all three populations, whereas H4 (28.5%) was shared by individuals from only two populations (GMZ and GLZ populations). This pattern of haplotype distribution highlights the genetic connectivity and variation across the zones, with H4 showing more limited distribution in the middle and lower zones of the Godavari River (Figure 11.2).

Figure 11.2: Distribution map of mitochondrial Cytb gene-based haplotypes and Haplotype-based median-joining network in *W. attu* populations in Godavari River. Each color represents a unique haplotype. The proportion of color in a population represents the frequency of particular haplotypes in that population.



11.3.2 Nuclear microsatellite genetic diversity

The nuclear genetic diversity was assessed using thirteen microsatellite markers in 76 individuals of *W. attu*. The mean values of Na, Ne, H_0 and H_e were 4.74 (±0.46), 3.01 (±0.31), 0.41 (±0.04) and 0.53 (±0.04). The H_0 was highest in the GMZ population (0.47) followed by GLZ population (0.45) and GUZ population (0.43). However, H_e was comparable across the populations viz., GUZ (0.54), GMZ (0.52), and GLZ (0.53). The estimated inbreeding coefficient (*F*) was positive in all populations, ranging from 0.07 to 0.17, with mean value 0.12 (±0.04). Due to deviation form Hardy Weinberg equilibrium, it potentially indicates the presence of inbreeding in *W. attu* populations (Table 11.2).

Table 11.2 Summary of microsatellite marker diversity in freshwater shark catfish populations based on thirteen microsatellites

Population	N	Na (±SE)	Ne (±SE)	Ho (±SE)	H_e (±SE)	F (±SE)
GUZ	24	4.38 (±0.62)	2.89 (±0.39)	0.43 (±0.07)	0.54 (±0.08)	0.17 (±0.08)
GMZ	27	4.53 (±0.80)	3.00 (±0.63)	0.47 (±0.08)	0.52 (±0.07)	0.07 (±0.08)
GLZ	25	5.30 (±0.96)	3.13 (±0.60)	0.45 (±0.08)	0.53 (±0.08)	0.12 (±0.06)
Overall	76	4.74 (±0.46)	3.01 (±0.31)	0.41 (±0.04)	0.53 (±0.04)	0.12 (±0.04)

Na: number of alleles, Ne: Number of effective alleles, Ho: observed heterozygosity, He: expected heterozygosity, F: Inbreeding coefficient

11.3.3 Pairwise genetic differentiation and Gene flow

The genetic differentiation (Fst) and gene flow (M) among the populations of *W. attu* was analysed using microsatellite data. The highest Fst was (0.032) measured between GUZ and GMZ populations while lowest was (0.017) measured between GMZ and GLZ population.

In case of gene flow, highest M (0.15 vs. 0.10) was observed between GMZ and GLZ population, whereas, lowest M (0.02 vs.0.04) was observed between GUZ and GMZ population. All the values for Fst are not correlating with genetic distance (Figure 11.3), however, asymmetrical values for gene flow was observed (Figure 11.4). The overall mean Fst measured at 0.03 (±0.01), suggested low genetic differentiation.

Figure 11.3
Pairwise Fst relationship between populations of *W. attu*

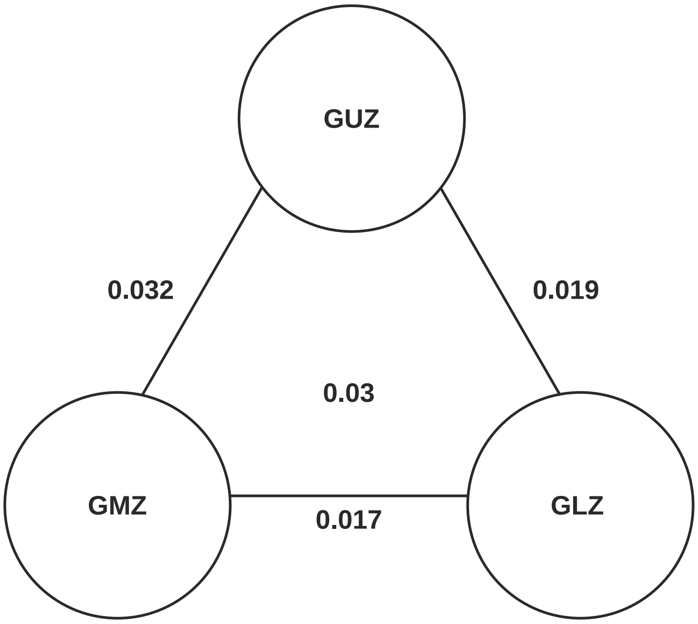
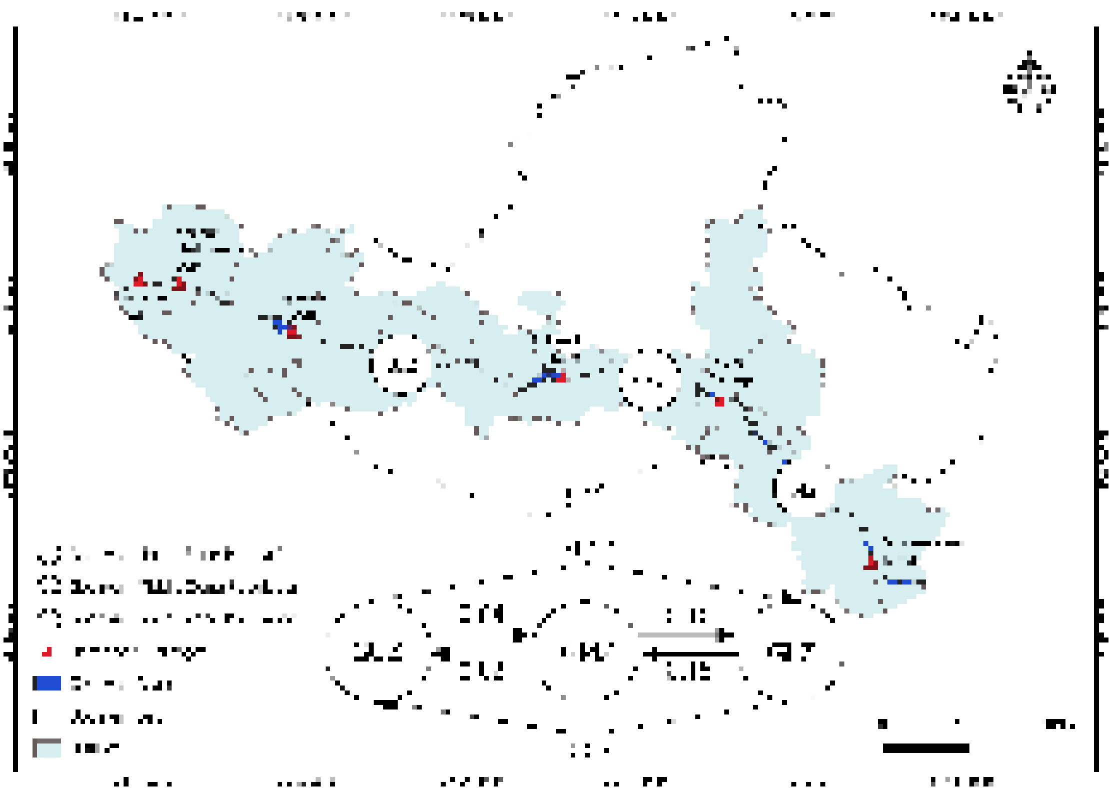


Figure 11.4
Values of recent migration detected with the BayesAss program for W. attu (GUZ, GMZ, and GLZ)



11.4 Population genetics of *Puntius sophore*

The alignment length of the COI gene in *P. sophore* was 672 base pairs, of which 582 were conserved, and 13 were variable sites with 5 were singleton, and 8 were parsimoniously informative. A total of thirteen substitutions sites was detected at nucleotide positions 66, 77, 82, 84, 97, 100, 115, 118, 169, 257, 344, 389, and 449 with reference to partial mitochondrial cytochrome oxidase gene (Gene bank Accession No.: MK572532.1).

Nine haplotypes (H1-H9) were identified based on nucleotide substitution sites (Figure 11.5). The haplotype diversity (Hd) and nucleotide diversity (p) were 0.76 (±0.08) and 0.0038 (±0.00095), respectively, suggesting high level of genetic diversity. The haplotype network showed a complex network with few missing haplotypes. Among 22 individuals, H2 was present in ten individuals, H5 was in five individuals while H1, H3, H4, H6, H7, H8 and H9 were present in a single individual only (Figure 11.5).

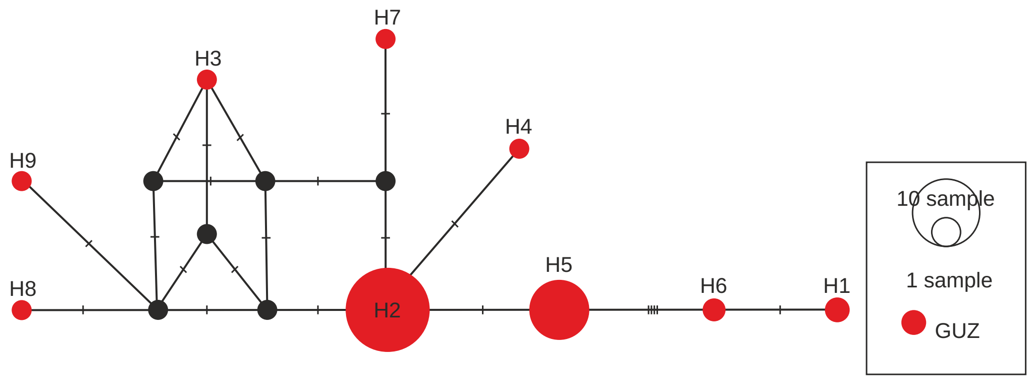


Figure11.5 Haplotype-based median-joining network inferred from COI gene in *P. sophore*. Each circle represents a unique

Haplotype and the size of the circle is indicative of the number of individuals present within the haplotype

11.5 Population genetics of *Devario aquepinnatus*

The alignment length of the COI gene in *D. aquepinnatus* was 654 nucleotide positions, of which 469 were conserved, 24 were variable sites with 18 singletons, and 6 were parsimoniously informative sites. A total of 24 substitution sites was detected at nucleotide positions 3, 7, 42, 52, 54, 57, 58, 79, 102, 104, 105, 127, 157, 173, 174, 284, 340, 398, 403, 421, 443, 492, 499, and 501 with reference to partial mitochondrial cytochrome oxidase gene (Gene bank Accession No.: JX983285.1). A total of nine haplotypes (H1-H9) were identified based on nucleotide substitution sites and represented a satellite structure (Figure 11.6). A high level of genetic diversity was observed in *D. aquepinnatus* in terms of haplotype diversity (Hd= 0.82 ±0.07) and nucleotide diversity (p =0.0076 ±0.00262).

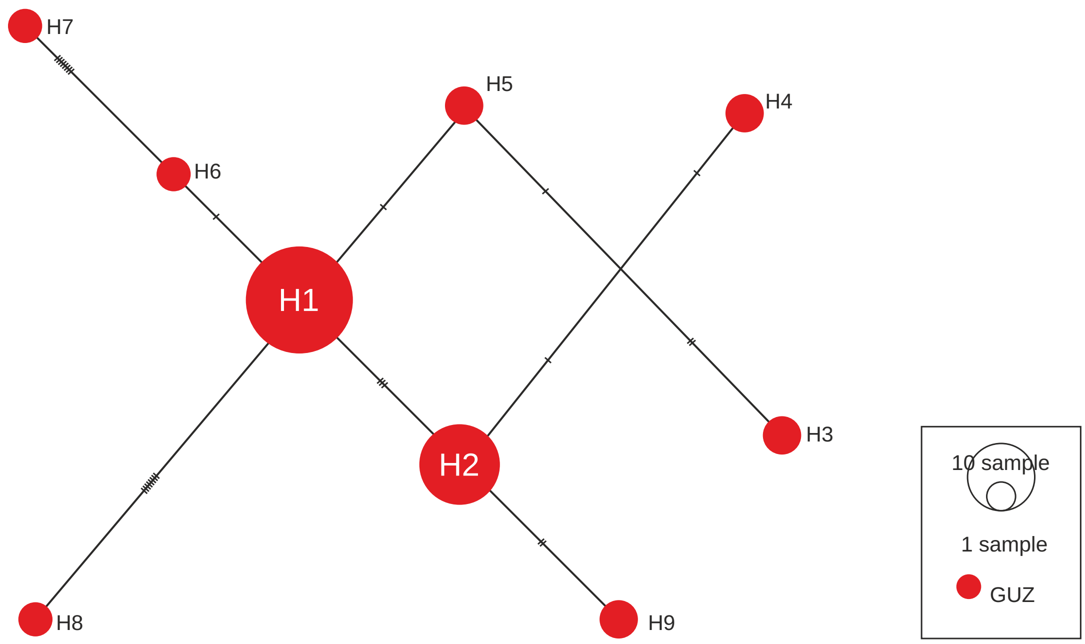


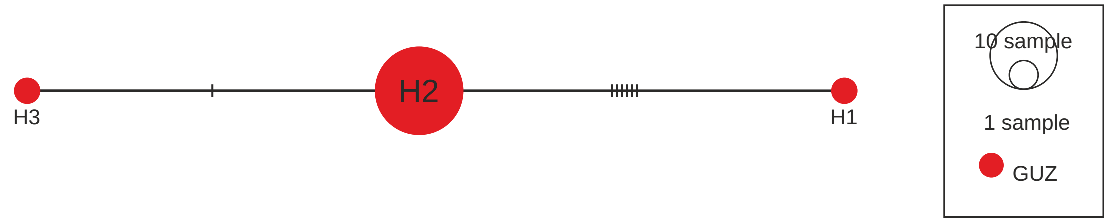
Figure11.6 Haplotype-based median-joining network inferred from COI gene in *D. aquepinnatus*. Each circle represents a unique haplotype and the size of the circle is indicative of the number of individuals present within the haplotype

11.6 Population genetics of *Garra mullya*

In *G. mullya* the alignment length of COI gene was 615 base pair. A total of eight substitutions sites were detected at nucleotide positions, 35, 130, 184, 199, 229, 268, 298, and 355 with reference to partial mitochondrial cytochrome oxidase gene (Gene bank Accession No.: JX983285.1).

Three haplotypes (H1-H3) were identified based on nucleotide substitution sites. A low level of genetic diversity was observed in G. mullya with haplotype diversity (Hd= 0.34 ±0.17) and nucleotide diversity (p= 0.0024 ±0.00163). The haplotype network showed a simple linear network. Among 11 individuals, H2 was present in nine individuals, while H1 and H3 were present in a single individual only (Figure 11.7).

Figure 11.7 Haplotype-based median-joining network inferred from COI gene in *G. mullya*. Each circle represents a unique haplotype and the size of the circle is indicative of the number of individuals present within the haplotype.



11.7 Discussion

In the present study, mitochondrial and nuclear microsatellite markers were used for assessment of genetic diversity and gene flow in *W. attu* of the Godavari River. Only mitochondrial markers were used for *P. sophore, D. aequipinnatus* and *G. mullya*.

Wallago attu exhibited a high haplotype and nucleotide diversity (Hd=0.643 and p= 0.00499). At the population level, the results highlighted a noticeable genetic gradient, with the GLZ population showing the highest genetic diversity. This results are aligned with previous findings in riverine fish populations, where downstream populations often exhibited higher genetic diversity due to more extensive unidirectional gene flow from upstream (Fraik et al., 2021, Vähä et al., 2008). The genetic diversity is comparatively lower in the current study than in earlier studies on Ganga and its tributaries populations, Indus and Chenab populations, but higher than the Ravi population. The difference in the genetic diversity could be due to certain anthropogenic factors (Kumar et al., 2021, Sherzada et al., 2024). Our analysis of the variation in the mitochondrial DNA Cytb exhibited four haplotypes (H1-H4) those are very less than previous finding in major river system of Indian rivers (Kumar et al., 2021, Sherzada et al, 2024, Sura et al., 2024). The high frequency of haplotype H2, which connects to all other haplotypes, suggests it may represent an ancestral lineage. Haplotype H4 was found in only two zones (WPZ5 and WPZ6) further emphasizes the limited gene flow between the upper, middle and lower zones. Overall findings suggest that barriers such as dams, varying river flow, and anthropogenic influences could create fragmented habitats, leading to lower gene flow and, consequently, reduced genetic diversity in these populations.

Microsatellite data suggested that observed heterozygosity in all three populations was almost similar,- with slightly higher genetic diversity in GMZ. This is also ecologically supportive, where the major tributary of the Godavari River, viz., Pranhita River, which carries waters from two large rivers, namely, Wardha and Wainganga, confluences to the middle reaches of the river Godavari. The admixing of these tributaries might lead to an increase in the genetic diversity of the *W. attu*. It was further supported by the low level of inbreeding in the GMZ population compared to the other two populations (GUZ and GLZ). Compared to previous studies, the Na, H_0, and H_e estimated for *W. attu* in this study were similar to Zafar et al. (2016) but lower than those reported by Singh et al. (2013) and Basharat et al. (2016).

A low level of genetic differentiation existed within the population. The study showed that individuals of *W. attu* in the middle and lower reaches of the river are well-connected, which is further supported by the genetic differentiation (Fst) values. However, pairwise Fst are not correlated with geographical distances. Interestingly, pairwise Fst values between GUZ vs. GLZ are relatively lower (0.019) than GUZ and GMZ (0.032) which are in close proximity. A possible explanation for the high genetic similarity of the upper population with the lower population could be due to the release of fingerlings by the state fisheries department at the Dowleswaram barrages (https://www.thehindu.com/news/national/andhra-pradesh/article67558522.ece). Additionally, it may be due to human interventions because these fish are edible and highly demandable in the market and exhibit a high degree of human-mediated dissemination.

The *P. sophore* and *D. aequipinnatus* populations exhibited high mitochondrial genetic diversity, with haplotype diversity (Hd) values of 0.76 and 0.82. The pattern of haplotypes in these species are suggested that they may have experienced rapid population expansions in the past, which would result in the accumulation of diverse haplotypes, as seen in the present study. These findings align with the results of Joshi et al. (2019) and Sudhasinghe et al., (2020), reported similar patterns of genetic diversity in these species, further supporting the notion of past population expansion events.

In contrast, *G. mullya* population showed lower genetic diversity, with a haplotype diversity (Hd) of 0.345. In the current study, this species is only collected from the upper reaches of river where water is clear, well-oxygenated with strong current and rocky substrates. However, their low genetic diversity could indicate loss of habitat due to damming, pollution from agricultural runoff or industrial discharges those might be affecting the population and availability of suitable breeding sites. In addition, it could be due to relatively smaller sample size in this study, which could contribute to the observed low diversity. Therefore, a larger sampling collection is required to substantiate the findings.

References

Basharat M, Shah HR and Hameed N (2016) Landslide susceptibility mapping using GIS and weighted overlay method: a case study from NW Himalayas, Pakistan. Arabian Journal of Geosciences, 9, 1-19.

Das S, Sangode SJ and Kandekar AM (2021) Recent decline in streamflow and sediment discharge in the Godavari basin, India (1965-2015). Catena, 206, 105537.

Fraik AK, McMillan JR, Liermann M, Bennett T, McHenry ML, McKinney GJ and Nichols KM (2021) The impacts of dam construction and removal on the genetics of recovering steelhead (Oncorhynchus mykiss) populations across the Elwha River watershed. Genes, 12(1), 89.

Hall TA (1999, January) BioEdit: a user-friendly biological sequence alignment editor and analysis program for Windows 95/98/NT. In Nucleic acids symposium series (Vol. 41, No. 41, pp. 95-98).

Joshi BD, Johnson JA, Negi T, Singh A, Goyal SP and Negi RK (2019) Understanding genetic diversity and population genetic structure of three Cyprinidae fishes occupying the same habitat from Uttarakhand, India. Mitochondrial DNA Part B, 3, 4(2), 2956-61.

Kumar G, Bano F and Serajuddin M (2021) Effect of formalin preservation on studies on morphology and condition factor of the freshwater shark Wallago attu (Bloch and Schneider, 1801) using truss network system. Indian Journal of Fisheries, 68(3).

Leigh JW, Bryant D and Nakagawa S (2015) POPART: full-feature software for haplotype network construction. Methods in Ecology & Evolution, 6(9).

Librado P and Rozas J (2009) DnaSP v5: a software for comprehensive analysis of DNA polymorphism data. Bioinformatics, 25(11), 1451-1452.

Peakall ROD and Smouse PE (2006) GENALEX 6: genetic analysis in Excel. Population genetic software for teaching and research. Molecular ecology notes, 6(1), 288-295.

Rahel FJ (2013) Intentional fragmentation as a management strategy in aquatic systems. BioScience, 63(5), 362-372.

Sherzada S, Hussain N, Hussain A, El-Tabakh MA and Khan SA (2024) Diversity and genetic structure of freshwater shark Wallago attu: an emerging species of commercial interest. Environmental Science and Pollution Research, 31(10), 15571-15579.

Singh A, Lakra WS, Mandhan RP, Goswami M, Yadav K and Sharma BS (2013) Isolation and characterization of polymorphic microsatellite loci in Wallago attu (Teleostei, Siluridae). Mol. Ecol. Res, 13, 546-549.

Sudasinghe H, Pethiyagoda R and Meegaskumbura M (2020) Evolution of Sri Lanka's Giant Danios (Teleostei: Cyprinidae: Devario): teasing apart species in a recent diversification. Molecular Phylogenetics and Evolution, 1, 149, 106853.

Sura S, Roy S, Mohapatra SK, Mishra AK, and Seth JK (2024) Haplotype analysis based on the D-loop region of mitochondria of the fish Wallago attu (Bloch and Schneider, 1801) collected from four major river basins of the Northern Part of the Eastern Ghats, India. Proceedings of the Indian National Science Academy, 1-9.

Vähä JP, Erkinaro J, Niemelä E and Primmer CR (2008) Temporally stable genetic structure and low migration in an Atlantic salmon population complex: implications for conservation and management. Evolutionary Applications, 1(1), 137-154.

Xiao W, Zhang Y and Liu H (2001) Molecular systematics of Xenocyprinae (Teleostei: Cyprinidae): taxonomy, biogeography, and coevolution of a special group restricted in East Asia. Molecular phylogenetics and evolution, 18(2), 163-173.

Zafar MM, Abbas K, Basharat H, Ahmad T and Hussain U (2016) Microsatellite DNA marker based genetic polymorphism in Wallago attu. Int J Bioinform Biol Syst, 1(2), 18-24.

12

STRETCHES OF CONSERVATION PRIORITY

12

STRETCHES OF CONSERVATION PRIORITY

Abstract

The Godavari River, flowing majorly through the Deccan peninsula biogeographic zone of India, sustains many threatened and endemic species of flora and fauna. Yet less than 20% (approx. 264 km) of the entire river is protected, which is terrestrial and accords incidental protection to the Godavari River. We delineated stretches of Conservation Prioritization Stretches in the Godavari River, employing the Ecological Niche Model (ENM) technique for conservation prioritization. A total of 677 km stretches of the Godavari River, including 304, 188, and 185 km in the upper, middle, and lower zones, respectively, was observed to be with suitable habitat for the following species, fish, birds, and mammals. Of the total stretches of biodiversity hotspot along Godavari River, 113 km falls under Wildlife Sanctuary and National Park. To ensure the long-term sustenance of biodiversity in these stretches, they could be designated under Category 4 of the IUCN (International Union for Conservation of Nature) and brought under the regulatory framework of the Wildlife (Protection) Amendment Act, 2022.

12.1 Introduction

Godavari River is the second largest river system (1,465 km) of Peninsular India. It originates from Trimbakeshwar in the Nashik district of Maharashtra at an altitude of 1,067 m asl. Godavari River flows from the eastern part of Western Ghats across the Deccan Plateau and opens into the Bay of Bengal (Pradhan et al. 2014). The Godavari basin is mainly spread over the states of Maharashtra, Telangana, Andhra Pradesh, Chhattisgarh, and Odisha, with small portions of Madhya Pradesh, Karnataka, and Puducherry. The entire basin of Godavari spreads over three biogeographic zones, i.e., Western Ghats, Deccan peninsula, and Coasts. Godavari basin is represented by several forest types, of which dry mixed deciduous forest dominates covering about 39563.65 Km^2 areas.

Godavari basin exhibit a rich diversity of flora and fauna. Godavari basin is home to 213 plant species, 80 species of butterflies, 33 species of odonata, 127 species of fish, 40 species of reptile, 384 species of birds (including 116 waterbirds), and 28 mammals (including one aquatic mammal) (NRCD-WII, 2022). The main channel of the Godavari River supports several threatened and near threatened taxa, including fishes such as *Parapsilorhynchus prateri* (Meolali Minnow), *Labeo potail* (Deccan Labeo), *Silonia childreni* (White Catfish),

Puntius fraseri (Dharna Barb) and *Cirrhinus cirrhosis* (Mrigal Carp), many birds species such as *Calidris pygmaea* (Spoon-billed Sandpiper), *Calidris tenuirostris* (Great Knot), *Sterna acuticauda* (Black-bellied Tern), *Rynchops albicollis* (Indian Skimmer) and *Ciconia nigra* (Black Stork), herpetofauna like *Lepidochelys olivacea* (Olive Ridley Turtle), *Crocodylus palustris* (Mugger) and *Lissemys punctata* (Indian Flapshell Turtle), and mammals such as *Lutrogale perspicillata* (Smooth-coated Otter). Additionally, the river is home to several endemic fishes, namely *Parapsilorhynchus prateri* (Meolali Minnow), *Puntius fraseri* (Dharna Barb), *Tor kulkarnii* (Dwarf mahseer), *Thynnichthys sandkhol* (Sandkhol carp), and *Clupisoma bastari* (Godavari Catfish).

However, this unique biodiversity face multiple anthropogenic pressures, such as industrial and agricultural pollution, low water level due to water abstraction from dams and barrages, habitat destruction is due to sand mining, sprouting populations of invasive species, and over exploitation of river resources (NRCD-WII, 2022). Protected areas have played a vital role in the conservation of many threatened and near threatened species of flora and fauna. Till now, a total of 264 km (18%) of the Godavari River is protected by chance while flowing through the six protected areas, namely, Jaikwadi WLS, Lanja Madugu Sivaram WLS, Pranahita WLS, Eturnagaram WLS, Papikonda NP and Coringa WLS.

Considering the lack of protection for the rich and threatened biodiversity of the Godavari River, there is a need to delineate stretches for the protection of unique biodiversity inhabiting the Godavari River for long-term sustenance of different species and maintaining Riverscape integrity. We delineated areas of conservation priority along Godavari River by assessing the habitat suitability for fish, birds, terrestrial mammals, and aquatic mammals. The proposed areas of conservation priority stretches represent the habitat suitability of all taxa present in the river.

12.2 Methodology

Stretches of Conservation Priority (SCP) in Godavari River was assessed by merging the habitat suitability for 22 species representing fish, birds, and mammals (Table 12.1). Ecological Niche Model (ENM) technique was employed to determine the suitable habitats for each species. We used the Maximum Entropy algorithm (MaxEnt) to predict habitats suitability for various fishes, birds and mammals. MaxEnt is a maximum entropy-based machine learning program for predicting the probability distribution using presence-only locations and a set of continuous and discrete environmental variables ' .

A total of 15 remotely sensed environmental variables representing topography (elevation and slope), water quality (pH, Dissolve Oxygen (DO), Electrical Conductivity, Water Temperature, Salinity, Flow Velocity, Total Dissolved Solids (TDS), Meteorological Data (rainfall), Geo-morphological Data (river depth, river width, soil, Land Use Land Cover (LULC) and Normalized Difference Vegetation Index (NDVI)) were used to assess the habitat suitability of selected taxa. The selection of layers for various species was based on their niche parameters. The interpolation technique, kriging was used to develop a raster layer for different water quality and anthropogenic pressure parameters. Table 12.2 highlights the source and method used to develop the raster layer for each environment layer to assess the habitat suitability. All the layers were downscaled to 30 m before using in MaxEnt software. Receiver Operating Curve (ROC) was used to evaluate the habitat suitability. The mean 10-percentile logistic training presence threshold value was used to define suitable and unsuitable areas. Habitat suitability values ranges from 0-1 and was divided into three classes of prospective distribution, namely less suitable (0-0.3), moderate suitable (0.3-0.5), and highly suitable (>0.5). All the predictive models of the various species were merged to determine the Stretches of Conservation Priority.

Table 12.1 List of environmental layers used for the distribution modelling of selected taxa of the Godavari River

Sl. No.	Environmental Layers	Class	Fishes	Water Birds	Mammals
1.	Elevation	Topography	✓	✓	✓
2.	Slope	Topography	✓	✓	✓
3.	Electrical Conductivity	Water quality parameter	✓	✓	✓
4.	Dissolved Oxygen (DO)	Water quality parameter	✓	✓	✓
5.	Flow velocity	Water quality parameter	✓	✓	✓
6.	pH	Water quality parameter	✓	✓	✓
7.	Salinity	Water quality parameter	✓	✓	✓
8.	Total Dissolved Solids (TDS)	Water quality parameter	✓	✓	✓
9.	Water Temperature	Water quality parameter	✓	✓	✓
10.	River Depth	Geo-morphology	✓	✓	✓
11.	River Width	Geo-morphology	✓	✓	✓
12.	NDVI	Geo-morphology	-	✓	✓
13.	Soil	Geo-morphology	-	✓	✓
14.	LULC	Geo-morphology	-	✓	✓
15.	Rainfall	Meteorological data	✓	✓	✓

Table 12.2: List of variables considered for the modelling habitat suitability in the Godavari River

Sl.No.	Name	Class	Sources	Method/ sources
1.	Electrical Conductivity	Water quality parameter	Primary data collected from field	Kriging method
2.	Dissolved Oxygen (DO)	Water quality parameter	Primary data collected from field	Kriging method
3.	Flow velocity	Water quality parameter	Primary data collected from field	Kriging method
4.	pH	Water quality parameter	Primary data collected from field	Kriging method
5.	Salinity	Water quality parameter	Primary data collected from field	Kriging method
6.	Total Dissolved Solids (TDS)	Water quality parameter	Primary data collected from field	Kriging method
7.	Water temperature	Water quality parameter	Primary data collected from field	Kriging method
8.	Elevation	Topography 30m digital elevation model (DEM) (https://earthexplorer.usgs.gov/)	Shuttle Radar Topography Mission (SRM)	
9.	Slope	Topography	SRTM DEM	Generated based on the elevation
10.	River depth	Geo-morphology	Field data	Kriging method
11.	River width	Geo-morphology	Field data	Kriging method
12.	NDVI	Geo-morphology	MODIS 250m	Generated GEE
13.	Soil	Geo-morphology	https://www.fao.org/	-
14.	LULC	Geo-morphology	National Remote Sensing Centre (NRSC) of the year of 2018-2019	-
15.	Rainfall	Meteorological data	https://worldclim.org/	

12.3 Stretches of Conservation Priority

A total of 677 km stretches, including 304 km in the upper zone, 188 km in the middle, and 185 km in the lower zone of the Godavari River, was found suitable for conservation of fish, waterbirds, and mammals (Table 12.3, Figure 12.1). In the upper zone, 30 km was suitable for 6-10 species, 92 km for 3-5 species, and 182 km for 1-2 species of birds, fishes, and mammals. In the middle zone, 64 km was suitable for 6-10 species, 85 km for 3-5 species, and 39 km for 1-2 species. In the lower zone, 33 km was suitable for 6-10 species, 71 km for 3-5 species, and 81 km for 1-2 species. Figures 12.1 to 12.4 visually illustrate the delineation of stretches of conservation priority in the upper, middle, and lower zones of the Godavari River.

Of the total suitable stretches of the Godavari River,113 km falls under the Wildlife Sanctuary and National Park, while the remaining are unprotected areas (Table 12.4). All the stretches of conservation priority of the Godavari River fall in the states of Maharashtra, Telangana and Andhra Pradesh.

Stretches of conservation priority were demarcated from Sangvi to Kanhegaon (26 km) in the upper zone. Medipalli coalmine to Medigadda barrage (84 km) in the middle and lower zone, and Iravendi Temple to Singanapalle (115 km) in the lower zone of Godavari River (Table 12.5).

Such information on stretches of conservation priority stretches/Biodiversity hotspots (the areas that support natural ecosystems and are largely intact, where native species and communities are associated with the ecosystem) is needed by the policymakers and decision-makers, including conservation organizations, for robust protection of rivers and streams through devising and implementation of suitable policies that permanently protect freshwater and the rights of communities that depend on them. In addition, this information is also supplementing the restoration of degraded freshwater ecosystems in the wake of myriad threats from extractive industries like mining and petroleum as well as agribusiness and cattle ranching, overfishing, industrialization of waterways, and urban industrial pollution.

Table 12.3 Stretches of conservation priority in Godavari River

River zone	Total zone length (km)	Suitable for 6-10 species (km)	Suitable for 3-5 species (km)	Suitable for 1-2 species (km)	Total Suitability (km)
Upper zone	691	30	92	182	304
Middle zone	318	64	85	39	188
Lower zone	453	33	71	81	185
Total length	1462	127	248	302	677

Table 12.4 Stretches of conservation priority falling in various Protected Areas in Godavari River

Protected Area	Stretches of Godavari River under Protected Area (km)	Suitable habitat stretches under Protected Area (km)
Jaikwadi WLS	74	33
Lanja Madugu Sivaram WLS	17	16
Pranahita WLS	3	3
Eturnagaram WLS	58	21
Papikonda NP	46	40
Coringa WLS	5	-
Total length	203	113

Table 12.5: Stretches of conservation priority falling in various zones of the Godavari River

River zone	Stretch length (km)	GPS Location		Location	District	State
		Start Location	End Location			
Upper zone	26	19.92615N74.37389E	19.79247N74.57902E	Sangvi to Kanhegaon	Ahilyanagar	Maharashtra
Middle and lower zone	84	18.7652N79.5778E	18.8308N79.4685E	Medipalli coalmine to Medigadda barrage	Peddapalii & Jayashankar	Telangana
Lower zone	115	17.74285N80.88080E	17.32455N81.62817E	Iravendi Temple to Singanapalle (Papikonda National Park)	East & West Godavari	Telangana and Andhra Pradesh

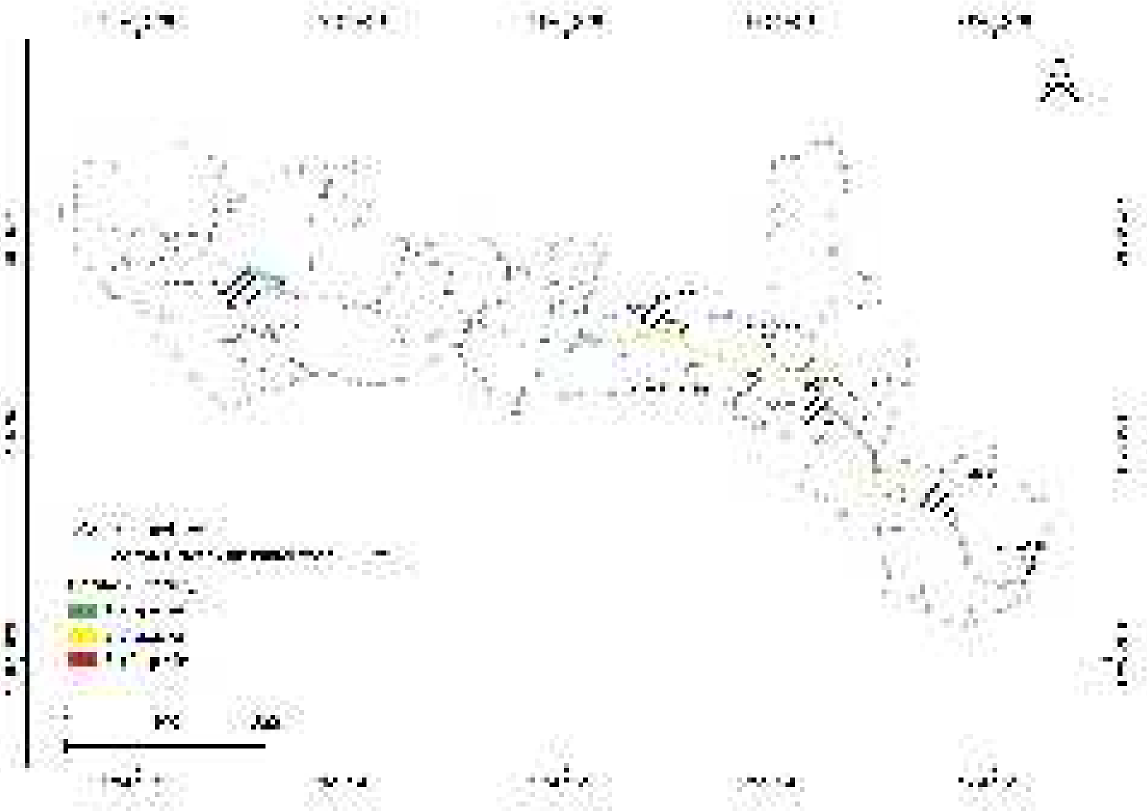


Figure 12.1
Stretches of conservation priority in Godavari River

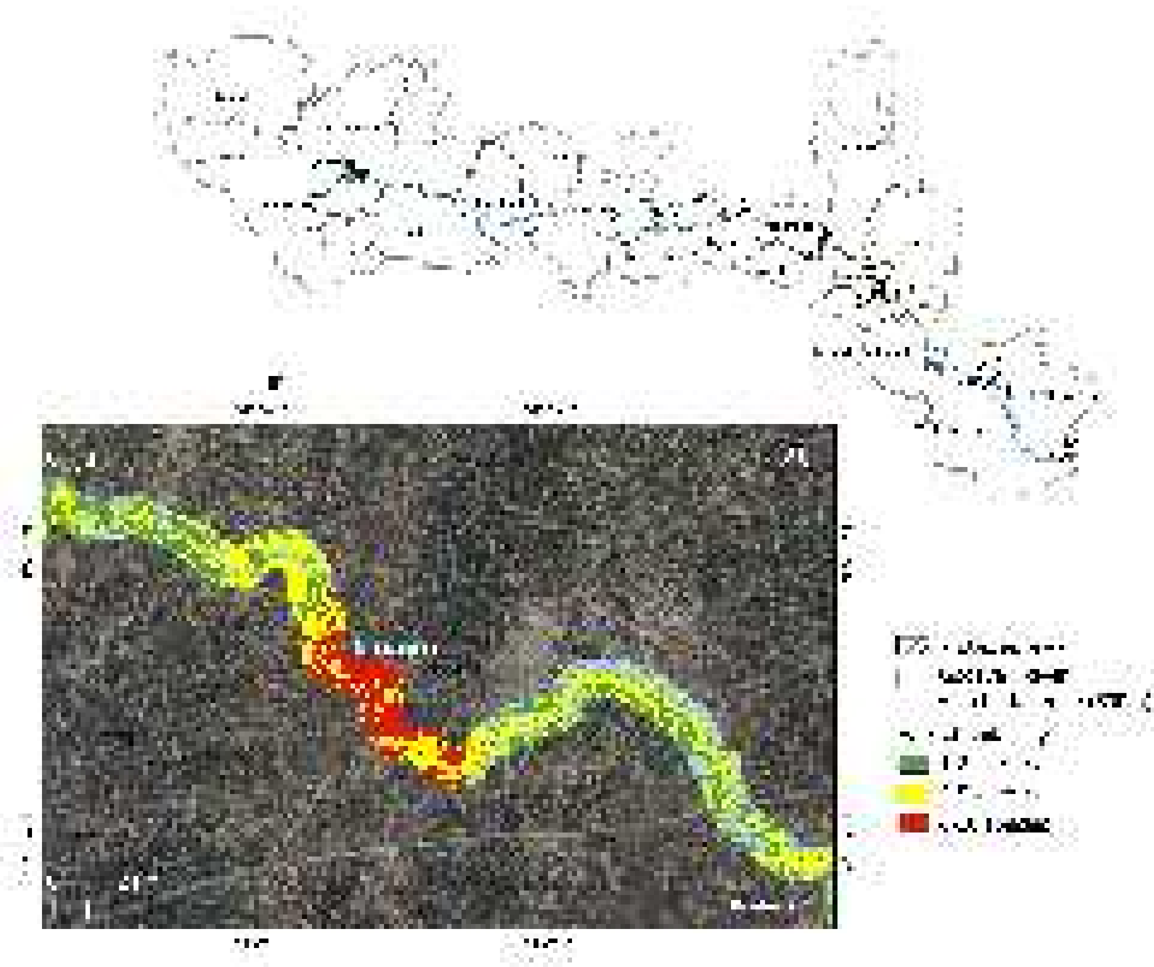


Figure 12.2
Stretches of conservation Priority in the upper zone of Godavari River

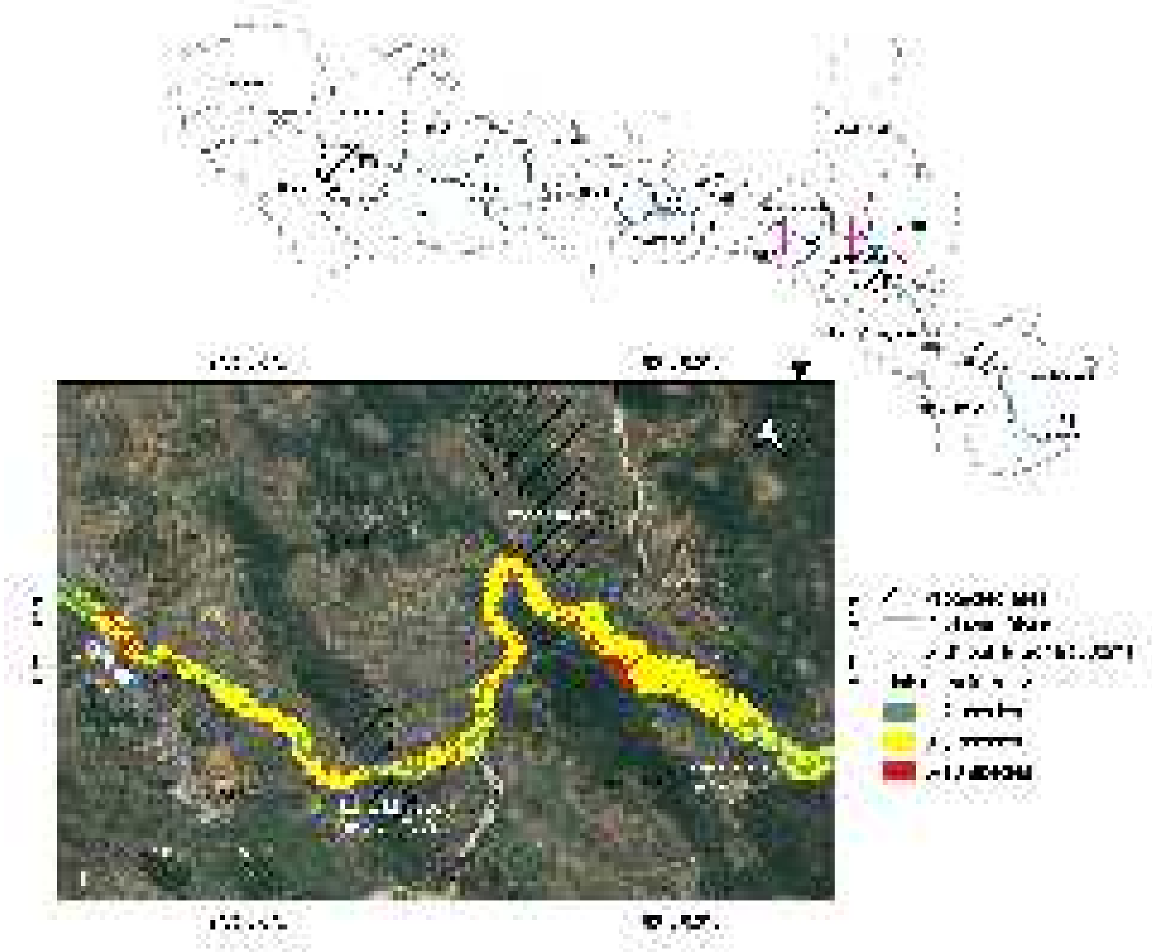


Figure 12.3 Conservation Prioritization Stretches in the middle & lower zone of Godavari River

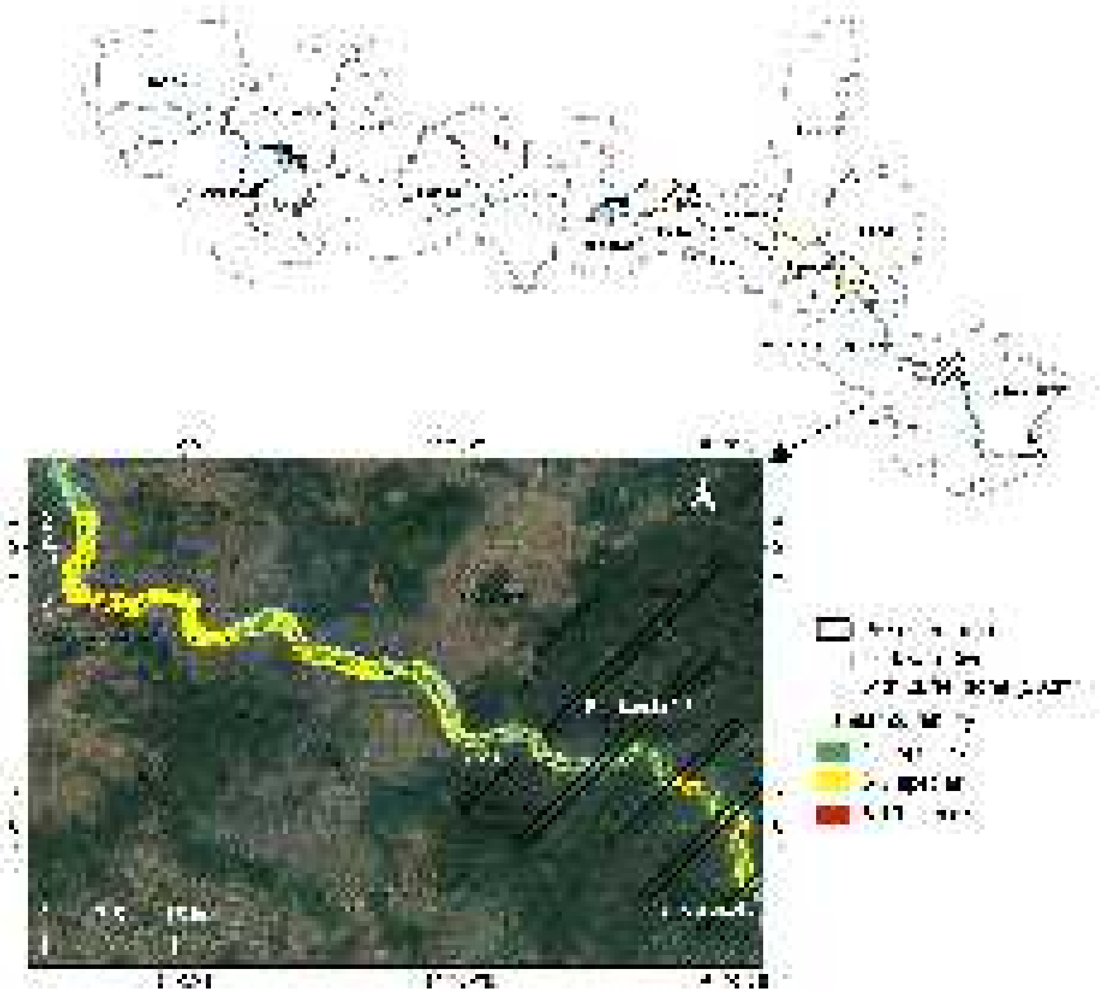
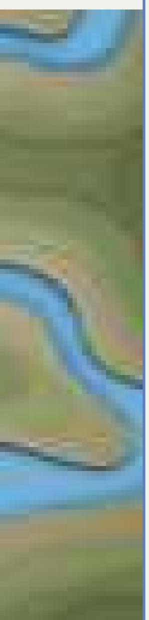


Figure 12.4 Stretches of conservation Priority in the lower zone of Godavari River

References

NRCD-WII (2022).Godavari Riverscape: Ecological status and trends. Ganga Aqualife Conservation Monitoring Centre, Wildlife Institute of India, Dehradun.Uttarkhand, India. pp.141

Pradhan UK, Ying WU, Shirodkar PV, Zhang J and Zhang G (2014). Multi-proxy evidence for compositional change of organic matter in the largest tropical (peninsular) river basin of India. Journal of Hydrology. 519.



13

CONCLUSION AND RECOMMENDATIONS

13

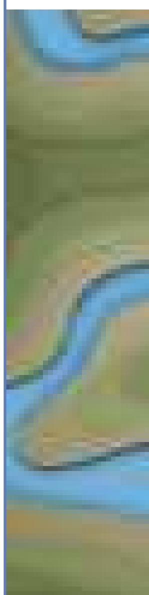
CONCLUSION AND RECOMMENDATIONS

The ecological assessment of the Godavari River provides an insight into the status and distribution of flora and fauna along with the river's health. The ecological assessment revealed that the Godavari River had low richness and abundances of trees and shrubs, but predominated by herbaceous vegetation. The Godavari River supports valuable carbon stock to mitigate climate change albeit in low amounts.

As far as the fauna is concerned, the Godavari River sustains a low richness of amphibians, waterbirds and terrestrial birds, a moderate richness of fish, a low richness of reptiles, and fair numbers of mammals. Moreover, aquatic mammals are absent in the Godavari River. Among the recorded species, almost 30% were fish, 33% amphibians, 26% were waterbirds and water-dependent/associated birds, and all the reptilian species had very narrow distribution and were recorded from only one sampling site, hence these species are susceptible to local extinction in the face of increasing anthropogenic pressure and pollution level in the Godavari River.

The dominance of *Prosopis juliflora* among trees *Lantana camara* among shrubs and *Alternanthera sessilis* among herbs indicate the predominance of invasive vegetation in the Godavari River. Five invasive fish species *viz*., *Cyprinus carpio*, *Hypophthalmicthys nobilis, Oreochromis mossambicus, Oreochromis niloticus*, and *Pygocentrus nattereri* occur in the Godavari River. The predominance of invasive vegetation and the occurrence of invasive fish is alarming, as these could replace the native fauna, and impact the vegetation and fish community structure, respectively in the Godavari River. Additionally, the fish community is dominated by the presence of small Indigenous fishes, such as *Osteobrama vigorsii, Chanda nama*, and *Systomus sarana* in comparison to economically important food fishes such as *Mystus vitatus, Wallago attu, Labeo calbasu*, and *Tor* species. This could potentially affect food security and livelihoods of community which is dependent on fishing. It could further impact the population of the species of conservation significance such as *Wallago attu* and Tor species.

The Godavari River supports low richness and diversity of flora and fauna with dominance of invasive plants. It also sustains several species of conservation concern. The presence of threatened and near-threatened species, including Schedule - I species of the Wildlife (Protection) Act -1972, amended 2022 accentuates the ecological importance of this river. The various species of conservation significance includes endangered birds such as Black-bellied Tern (*Sterna acuticauda*), Indian Skimmer (*Rynchops albicollis*), vulnerable birds such as Common Pochard (*Aythya ferina*), River Tern (*Sterna aurantia*) and and near threatened birds such as Grey-headed Fish-Eagle (*Icthyophaga ichthyaetus*), Woolly-necked Stork (*Ciconia episcopus*), Painted stork



(*Mycteria leucocephala*), Black-tailed Godwit (*Limosa limosa*), Alexandrine Parakeet (*Psittacula eupatria*), Oriental Darter (*Anhinga melanogaster*), Black-headed Ibis (*Threskiornis melanocephalus*), near threatened fish such as *Chitala chitala* also found in the Godavari River. Blackbuck, Schedule-I species that occurs in the Godavari River. This indicated that the Godavari River is vital for the conservation of various globally threatened species.

Godavari River and its biodiversity confront a multitude of pressing conservation challenges such as grazing, water extraction, fishing, waste disposal, sand mining, ferry, free-ranging dogs, bathing ghats, religious ghats, development, cremation, aquatic vegetation extraction, and brick kiln. Additionally, Godavari water is polluted due to heavy metals particularly nitrate, chromium, cadmium, lead, and mercury, that were present beyond the permissible limit further aggravating the situation. Unregulated grazing may contribute to soil erosion and habitat disruption, further disrupt the delicate balance of the ecosystem. Water abstraction practices, often driven by agricultural and industrial needs, can result in altered flow patterns and negatively impact aquatic habitats. Activities such as fishing pose a threat to aquatic species, mainly impacting their populations. Mining activities can lead to habitat destruction and water quality degradation, adversely affecting both flora and fauna. The presence of bathing ghats may contribute to habitat disturbance and water pollution, posing challenges to the conservation of biodiversity in the Godavari River. Pollution from industrial outlets poses a significant risk to water quality, while improper waste disposal from domestic and religious activities introduces pollutants that can harm the river's ecosystem.

The present study suggests that the ecological values of the Godavari River can be sustained through proper management practices. Therefore, it is imperative to prioritize and implement comprehensive conservation strategies to safeguard the invaluable biodiversity of the Godavari River and ensure the long-term survival of these ecologically significant species.

Local communities, political entities, and environmental organizations must work together to address these conservation concerns. In order to guarantee the long-term health and resilience of this essential ecosystem, it is imperative to implement sustainable practices, enforce legislation, and increase public understanding of the significance of protecting the biodiversity of the Godavari River. In light of these, the Godavari River's sustainability is advised to be protected by the following conservation actions.

Recommendations for Conservation of the Godavari River

1. Confederation of regional institutes and departments

River management requires an integrated multi-agency and multi-disciplinary approach to data sharing, planning and implementation. A combination of engineering, technological, social, economic and legal expertise is needed to manage the water resources. This requires coordination across departments and administrative regions from central government down to provincial government levels. The establishment of new institutional arrangements is imperative to ensure the long-term sustainability of the Godavari River. Therefore,

I. A confederation on the Godavari River is proposed, which would serve as a nodal body to coordinate between various agencies within and outside the state in terms of accessing information, sharing knowledge, reports, plans and updates on implementation, studies, projects in pipelines and funding sources (Figure 13.1). The confederation would coordinate with research institutions, universities and other professional agencies conducting studies on the hydrology, climate and hydro disaster related aspects impacting the state. This confederation would be well conversant with the evolution of national and state policies & laws and will serve as the knowledge partner for all the stakeholder agencies involved in water resource management in the state. This collaborative and diverse composition will facilitate effective decision-making, policy formulation, and implementation, fostering a holistic strategy for the sustainable management and conservation of the Godavari River in the future.

ii. The confederation would develop a master plan for river conservation and rejuvenation involving multiple stakeholders to take timely actions for the conservation of the Godavari River, its biodiversity and meeting human needs.

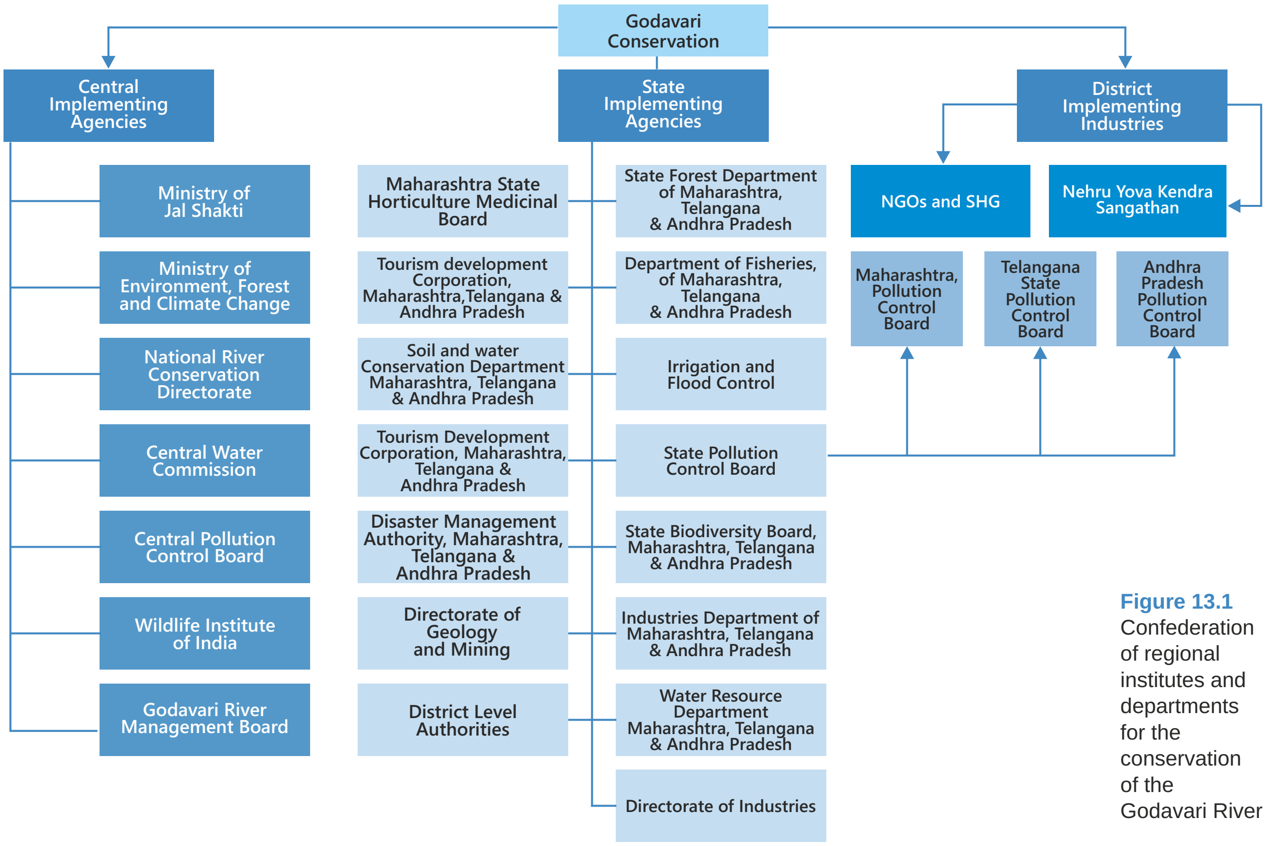


Figure 13.1 Confederation of regional institutes and departments for the conservation of the Godavari River

2. Maintaining the natural flow of the river

Godavari River is highly fragmented due to the construction of 26 Dams including Nathsagar dam in Maharashtra, Sriram Sagar/ Pochampa dam in Telangana and Pedallareddy dam in Andhra Pradesh. Hon'ble National Green Tribunal (NGT) in OA 498 of 2015 has directed all States to maintain a minimum environmental flow of 25-30% of the average lean season flow in their rivers. Therefore, it is recommended that

I. The Water Resources Department of the respective states should ensure a minimum environmental flow of 25-30% of the average lean season following the directions of the National Green Tribunal, the River and Canal Act 1863, and the Minimum Water Flow Protection Act, 1977.

ii. Central Water Commission should ensure the minimum flow of the Godavari River in each state to maintain the required environmental flow of the Godavari River to safeguard the flow regimes, riparian habitat, aquatic biota, diversity etc. in the river

iii. Water Audits should be carried out jointly with the Central Water Commission and the Water Resource Departments of the respective states.

3. Biodiversity Conservation

The Godavari River and its biodiversity are in a meagre state. A network of Protected Areas is imperative, to conserve the existing biodiversity of the river. About 375 km of the river stretch encompassed habitat that was suitable for 3 to 10 species (Table 12.3) and about 302 km of the river stretches for one to two species. Only, about 14% (203 km) of the Godavari River receive protection due to flowing through six Protected Areas, namely Jaikwadi WLS, Lanja Madugu Sivaram WLS, Pranahita WLS, Eturnagaram WLS, Papikonda NP and Coringa WLS. Therefore, the following recommended conservation actions are to be taken up.

I. About 375 km should be designated as Category 4 of the IUCN (International Union for Conservation of Nature) i.e. Habitat/Species Management Area and brought under the regulatory framework of the Wild Life (Protection) Act, 1972, amended in 2022. The remaining 302 km should be regarded as a restoration zone for various restoration activities.

ii. In the face of increasing human pressure, it is important to monitor biodiversity at regular intervals to assess the impact of anthropogenic pressures and evaluate the effectiveness of conservation efforts that will help to develop and take up adoptive measures. Therefore, concerned forest departments should regularly monitor the biodiversity at regular intervals following the protocol for biodiversity monitoring, at the recommended frequencies as outlined in Table 13.1. This monitoring framework will provide valuable insights into the changing dynamics of the ecosystem, helping to adapt and refine conservation strategies as needed. Regular assessments ensure a proactive approach to address environmental challenges and contribute to the long-term conservation and sustainability of the Godavari River biodiversity.

iii. The biodiversity of the Godavari River could be highlighted through awareness /education among locals/peoples to conserve the river in this peninsular region of the country. Therefore, an interpretation center should be developed at the Nandhur and Jaikawadi Wildlife Sanctuary in Maharashtra, and upgrade the interpretation Centre and highlight the biodiversity of the Godavari River and its importance at Shivavari Crocodile Wildlife Sanctuary, and Papikonda NP in Andhra Pradesh. This could serve as an appropriate effort of awareness/education among locals/peoples to conserve the river and its biodiversity.

iv. Riparian vegetation cover is a key factor affecting aquatic species, their movement, and dispersal. The riparian zone had a very low density of trees, particularly native vegetation. Therefore, it is recommended that forest departments of all states should initiate reforestation of banks leveraging native riparian species to increasing green cover.

v. There is predominance of the invasive plant species such as *Prosopis juliflora* among trees, *Lantana camara* among shrubs, and *Alternanthera sessilis* among herbs on the bank of the Godavari River. It is recommended that Forest Department of all different states in collaboration with Vana Samrakhana Samithi of the concerned states and take appropriate steps in eradication of the invasive species and plantation of native vegetation.

vi. Additionally, there are several invasive fish viz., *Cyprinus carpio, Hypophthalmicthys nobilis, Oreochromis mossambicus, Oreochromis niloticus*, and *Pygocentrus nattereri* in the Godavari River. State Forest Departments along with the National Fisheries Development Board, Hyderabad, and Department of Fisheries of the concerned states should regularly monitor and take appropriate steps to eradicate the invasive plant species and invasive fishes.

Table 13.1: Recommended biodiversity and respective monitoring activities in the Godavari River

Parameters	Indicators	Scale	Monitoring method	Monitoring frequency
Habitat monitoring				
Land use/ Land cover changes	% area under various land use and cover classes (agriculture, forest cover, settlements, wetlands, mining)	River/flood Zone	GIS and Remote Sensing Radar sensed data	Once in 10 years
Invasive species monitoring	Invasive weed species such as *Prosopis Juliflora, Lantana camara, Parthenium hysterophorus, Ageratum conyzoides* etc.	Riparian zone	Standard procedure	Initially once every year for 3-5 years and then onwards once in two years
Vegetation and their Regeneration Status			Standard procedure	Once a year
Water quality		River	Eco-toxicological studies	Annually
Fauna	Invertebrates Birds (aquatic and water-dependent) Fish Mammals (aquatic)	River/Flood Zone	Standard procedure Standard procedure Standard procedure Standard procedure	Annually

4. Pollution

The Godavari River, one of India's most important water bodies, is significantly impacted by industrial activity along its course. Industrial pollution significantly contributes to environmental contamination, including both heavy metal pollution and endocrine-disrupting chemicals (EDCs) pollution. Heavy metals such as lead, mercury, cadmium, and chromium originate from industries like mining, electroplating, and chemical manufacturing, persisting in water bodies and sediments due to their non-biodegradable nature. These metals bioaccumulate in aquatic organisms, leading to toxicity, physiological stress, and potential human health risks. Similarly, EDCs-found in plastics, pesticides, pharmaceuticals, and industrial chemicals-interfere with hormonal systems, disrupting reproduction, growth, and metabolism in both wildlife and humans.

Industrial Pollution

In our present study, concentrations of Cadmium, Lead, and Mercury in water and Chromium in sediment exceeding than the permissible set by for aquatic life. The sources of cadmium and lead are industries, detergents, paints, fertilizers, and cheap plastic. Hence its occurrence indicated heavy domestic/industrial discharge and agriculture run-off in the Godavari River. The sources of Chromium are electroplating industries and inorganic chemical plants, and mercury occurs due to discharge from cement plants, coal-fired power stations, and cremation and mining. Thus, their occurrence depicted industrial pollution and pollution due to human activities. In our current study, the polluted stretches include Nanded, Nashik, and Aurangabad (Maharashtra), and the Mancherial region (Telangana). There are 711 industries in Nanded (Major industries are Agrobase and Engineering industries), 2547 industries in Nashik (Engineering and Automobile Industries), and 2123 in Aurangabad. In Andhra Pradesh, wood-based pulp and paper generation units and sugar mills are polluting the Godavari River stretches between Rayanpeta and Rajamahendravaram (CPCB, 2020). In Mancherial, there are 73 industries including a coal mine and Thermal Power plants (https://tspcb.cgg.gov.in/),

Therefore,

I. State Industrial Developmental Cooperation and State Pollution Control boards should ensure the presence of Effluent Treatment plants in each industry.

II. The State Industrial Development Corporations of each state should be responsible for establishing the Common Effluent Treatment Plant (CETP) in areas with high levels of heavy metal pollution, with a particular emphasis on the MIDC Satpur, Nanded MIDC region, MIDC Shendra, Mancherial and Rajahmundry.

III. The State Industrial Development Corporations of each state are responsible for upgrading the Common Effluent Treatment Plant (CETP) with a particular emphasis on the MIDC Area Waluj

IV. The State Industrial Development Corporations of each state are responsible for making the operation of the Common Effluent TreatmentSewage pollutionPlant (CETP) with regular monitoring viz, to CETP in MIDC Waluj Phase-II, MIDC Shendra.

V. The State Industrial Development Corporations of each state are responsible for Construction or if already existing Upgradation of separate CETP for electroplating industries viz, Waluj MIDC.

VI. The State Pollution Control Board in consultation with the should regularly monitor the water quality of the Godavari River. vii. State Pollution Control Boards of all three states should inspect industries, and Effluent Treatment plants periodically.

VII. Municipality should inspect the unauthorized industrial discharge and impose penalties in consultation with the state Pollution Control Board.

EDCs pollution

Hotspot of the EDCs including Pesticides and chemical fertilizers pollution were observed between Nashik, Naded, and Karimnagar districts.

Therefore,

I. It is recommended that respective Maharashtra Pollution Control Boards (MPCBs) in collaboration with Department of Agriculture, Cooperation and Farmers Welfare (DAC&FW), Ministry of Agriculture, and Central Pollution Control Board is recommended to regularly monitor EDCs pollution inclusion of Pesticide and other chemical compounds residues in Godavari River under Insecticides Act 1968 in Integrated Pest Management, (IPM) Programme.

II. Additionally, Maharashtra Pollution Control Boards (MPCBs) should also organize trainings on IPM at grassroots level through farmer filled school (FFSC).

Sewage pollution

The river directly receives sewage from townships viz. Nashik, Chakratirth, Odha, Kopargaon, Paithan, Pathri, Nanded, Kandakurthi, Gangama temple, Mancherial, Kaleswaram, Polavaram, Kapileswram, Rajahmundry and Yanam. Approximately, 15892 MLD of sewage is generated from urban and rural areas along the course of the Godavari River. The dissolved oxygen (DO) was low in Nanded, Triambak (Nashik), Odha (Nashik), and ChakraTirth (Nallah) in the state of Maharashtra indicating heavy sewage pollution in these river stretches. In Maharashtra, Chunal Nallah (Nanded), Chikhali Nallah, Gangapur Nallah, Bardan Pahta Nallah, Someshwar, Nallah, Anadwali Nallah (Nasik), Kaplicha nallah, and Gangakhed, Parbhani (Gangakhed city) directly discharge domestic sewage into the Godavari River. In Andhra Pradesh, Nallah channel, Ava drain, and Mallayyapta drain discharge domestic sewage in the Godavari River between Rayanpeta and Rajahmundary.

Therefore,

i. Pollution control board of respective states should monitor the water quality of the Godavari River regularly. Pollution control board of respective states are recommended to monitor the STPs for compliance.

ii. Municipal cooperation of each of the aforementioned region should augment and revamp the existing STP and increase the capacity of STP so as to treat more sewage generated in the municipality.

iii. Municipal Administration and Urban Development Department in the state of Andhra Pradesh should construct proposed Sewage Treatment Plant (Proposed: 5 MLD +28 MLD) for treatment of the remaining sewage generated by Rajahmundary town.

iv. In Maharashtra, Chunal Nallah (Nanded), Chikhali Nallah, Gangapur Nallah, Bardan Pahta Nallah, Someshwar, Nallah, Anadwali Nallah (Nasik), Kaplicha nallah, Gangakhed, Parbhani (Gangakhed city) directly discharge domestic sewage into the Godavari River. In Andhra Pradesh, Nallah channel, Ava drain and Mallayyapta drain discharge domestic sewage in Godavari River between Rayanpeta and Rajahmundary. Therefore, the concerned municipalities are recommended to divert the domestic sewage channels/Nallahs to STPs

v. State Pollution Control Boards of the respective states should inspect flats, hotels, Sewage Treatment plants periodically.

vi. District administration should strictly check the unauthorized dumping in the river.

Waste dumping

To promote sustainable and improved practices for waste management through the collection, segregation, and treatment of solid wastes, it is recommended that

i. Concerned municipalities of each district are recommended to dredge out the municipality solid waste dump from the river bank and process the solid waste in the Solid Waste Generation and Processing Unit of Paithan, Ganga Khed, Nanded and Nashik (Maharashtra), Bhadrachalam, Ramagundam (Telangana), and Rajahmundry (Andhra Pradesh).

ii. Concerned municipalities of each district along the course of the Godavari River should install and maintain proper waste disposal infrastructure, such as trash bins and recycling facilities along the bank and in recreational areas, bathing ghats, and religious ghats to prevent the solid waste being thrown into and on the bank of the Godavari River.

iii. Concerned municipalities of each district along the course of the Godavari River should install plastic shredding units.

iv. Pollution control boards of respective states and concerned municipalities along the course of the Godavari River should spread awareness on processing segregation, and disposal of waste in urban areas.

v. Concerned municipalities of each district are recommended to collect the Nirmalaya left in the river during festivals, religious rituals, and during melas.

vi. The use of National Institute of Hydrology (NIH) based phytoremediation techniques, eg. Constructed wetlands are recommended for the purification of wastewater and entry of the putrescible organic matter into the mainstream of the Godavari River. Moreover, National Environmental Engineering Research Institute (NEERI) based techniques are recommended for solid waste management.

vii. Forest Department should create/develop riverine buffers near agriculture fields and urban settlements to restrict the urban and agricultural hazardous chemicals runoff directly into the River.

viii. Encourage the reduction of waste at the source through education and awareness programs. Educate local communities about the importance of responsible waste disposal and its impact on river health. People should be encouraged to participate in clean-up events to remove existing waste from riverbanks and surrounding areas by involving them in various national-level initiatives such as Nadi Utsav, Swachh Bharat Abhiyan, Mission LiFE (Mission Lifestyle for Environment) under the Green Credit Programme, 2023 etc.

5. Anthropogenic pressure

Water abstraction

Water abstraction is rampant in the entire stretch of the Godavari River. As per the Hon'ble National Green Tribunal (NGT), all States are to maintain a minimum environmental flow of 15-20% of the average lean season flow in their rivers. Therefore, the following recommendations are suggested:

i. The Water Resources Department of the concerned states in consultation with the Central Water Commission is recommended checking the unauthorised water abstraction of the Godavari River to maintain the eFlow under National Green Tribunal, 2015 guidelines.

ii. The Water Resources Department need to monitors the quantity of water abstraction by different users in the Godavari basin.

iii. The Water Resources Department of the concerned states should set scientifically informed limits on the volume of water that can be abstracted from the river, taking into consideration ecological flow requirements and sustainable water yields. Ensure that abstraction rates leave sufficient water in the river to support aquatic habitats, fish migration, and overall ecosystem health of the river.

iv. District administration imposes restrictions on unauthorized water abstraction during periods of low flow to protect aquatic ecosystems.

Cattle grazing

i. Cattle grazing need to be regulated by issuing grazing permits to villagers under the grazing policy and forest rules of the concerned state forest Departments.

ii. Spreading awareness among villages about the adverse impact of cattle grazing is also required and highly imperative.

Fishing

Fishing activities were noted along almost the entire stretch of the Godavari River. However, they are more prominent in the middle zone particularly around Aloor, Nizamabad District. Therefore, it is recommended that

i. Forest Departments of the Telangana and Maharashtra are recommended to implement and enforce fishing regulations to control the types of gear used, catch limits, and seasons of fishing (avoid breeding season). Set and enforce size limits on fish to be harvested to allow them to reach maturity and contribute to breeding.

ii. Fishing should be regulated in all fish hotspot stretches in the Godavari River viz., Mardasgaon to Dhalegaono (Prabani district), Pimplgaon to Navghat Bridge (Nanded district), Digras Chirli Bridge to Puskar ghat Saangvi (Nanded & Nirmal district), Medipalli coalmine to Singaram (Jayashankar), Kapavaram to Chingurumamidi (Mulugu district) and Tummileru to Trilingeswara temple (East Godavari district).

iii. Restocking of the native fish should be encouraged to increase the abundance of the population of native fish in the Godavari River.

iv. Identify spawning areas of the fish and implement seasonal closures to protect vulnerable life stages (June to August).

v. Educate fishermen about sustainable fishing practices, including the importance of catch-and-release, responsible gear use, and compliance with regulations.

vi. Educate fishermen on how to release unintended captures, such as turtles, snakes, or birds, in the event of accidental capture. Moreover, fishermen should be encouraged to use such fishing gear that minimizes unintended bycatch.

vii. Raise awareness among the general public about the importance of sustainable fisheries.

viii. Introduce economic incentives for communities or individuals who actively contribute to fish conservation, such as through sustainable fishing practices or habitat restoration efforts.

Table 13.2: Summary of the proposed recommendation for the conservation of the Godavari River, its biodiversity and Policies

RECOMMENDATION	TASK TO BE PERFORMED	IMPLEMENTING AGENCIES
Institutional Arrangements	Preparation of a master plan for the conservation of the Godavari River	**Central Agencies** • Ministry of Jal Shakti (MoJS) • Ministry of Environment, Forest and Climate Change (MoEFCC) • National River Conservation Directorate • Godavari River Management Board • Central Water Commission • Central Pollution Control Board • Wildlife Institute of India
		State Agencies • State Forest Department of Maharashtra, Telangana and Andhra Pradesh • Department of Fisheries of Maharashtra, Telangana and Andhra Pradesh • Directorate of Industries of Maharashtra, Telangana and Andhra Pradesh • Irrigation and Flood Control of Maharashtra, Telangana and Andhra Pradesh • State Biodiversity Board of Maharashtra, Telangana and Andhra Pradesh • Industries Department of Maharashtra, Telangana and Andhra Pradesh • Pollution Control Board of Maharashtra, Telangana and Andhra Pradesh • School Education and Sports Department of Maharashtra, Telangana and Andhra Pradesh • Disaster Management Authority of Maharashtra, Telangana and Andhra Pradesh • Directorate of Geology and Mining of Maharashtra, Telangana and Andhra Pradesh • State Horticulture and Medicinal Board of Maharashtra, Telangana and Andhra Pradesh • Tourism Development Corporation of Maharashtra, Telangana and Andhra Pradesh • Water Resource Development Authority of Maharashtra, Telangana and Andhra Pradesh • Soil and Water Conservation Department of Maharashtra, Telangana and Andhra Pradesh • NGOs & SHG of Maharashtra, Telangana and Andhra Pradesh • District-level Authorities of Maharashtra, Telangana and Andhra Pradesh
Maintaining the E-flow of the river	Environment Impact Assessment Prior to Dam Construction	• Central Water Commission • Maharashtra Water Resources Regulatory Authority • Telangana Water Resources Development Cooperation Ltd. • Water Resources Department, Government of Andhra Pradesh
	Establishment of Protected Area	• Maharashtra Forest Department • Telangana Forest Department • Andhra Pradesh Forest Department
	Biodiversity Monitoring	• Maharashtra Forest Department • Telangana Forest Department • Andhra Pradesh Forest Department • State Biodiversity Board • Academic institution • NGOs

RESPONSIBLE AUTHORITY	POLICY
MoEFCC MoJS	• Indian Fisheries Act, 1897 • Wild Life (Protection) Act, 1972 • Forest Conservation Act, 1980 • Biological Diversity Act, 2002 • National Environment Policy, 2006 • National Biodiversity Action Plan (NBAP), 2008 • Water (Prevention and Control of Pollution) Act, 1974 • Water (Prevention and Control of Pollution) Cess Act, 1977 • Environment (Protection) Act, 1986 • Environment (Protection) Rule, 1986 • The Inter-State River Water Disputes Act, 1956 • River Boards Act 1956 • National Water Policy 2012 • Sustainable Sand Mining Management Guidelines, 2016 • E-Waste Management Policy (2017) • The Rivers and Canals Act (1863)
Principal Secretary & Principal Chief Conservator of Forest (PCCF)	**Maharashtra** • Maharashtra Biological Diversity Rules (2008) • Maharashtra Forest (Protection) Act (1975) • Maharashtra State Forest Policy (2008) The Maharashtra Fisheries Act (1960) **Telangana** • Andhra Pradesh Fisheries Act (1951) Telangana Sand Mining Policy (2014) **Andhra Pradesh** • Andhra Pradesh Sand Mining Policy (2019) • The Andhra Pradesh Fisheries Act (1951) • Andhra Pradesh Inland Fisheries Act (1997) • Andhra Pradesh (Andhra Area) Rivers Conservancy Act (1884)
MoJS	• Hon'ble National Green Tribunal (NGT), 2015 • The Rivers and Canals Act, 1863 • The Minimum Water Flow Protection Act ,1977
Head, Forest & Wildlife Department of concerned state	• The Environment (Protection) Act, 1986 • The Wild Life (Protection) Act, 1972 • The Biological Diversity Act, 2002
Head, Forest & Wildlife Department of concerned state	• Wildlife (Protection) Act, 1972 • Biological Diversity Act, 2002

RECOMMENDATION		TASK TO BE PERFORMED	IMPLEMENTING AGENCIES
Biodiversity Conservation		Development of the Interpretation Centre	• Maharashtra Forest Department • Andhra Pradesh Forest Department • Telangana Forest Department
		Reforestation of banks leveraging native riparian species	• Maharashtra Forest Department • Andhra Pradesh Forest Department • Telangana Forest Department
		Restocking of the native fish in the Godavari River	• National Fisheries Development Board, Hyderabad • Department of Fisheries of the concerned state • Central Inland Fisheries Research Institute, Andhra Pradesh
		Enforce fishing regulations	• State Fisheries Department • State Forest Department
Pollution abatement	Industrial pollution	• Ensure the presence of Effluent Treatment plants in each industry • Install the Common Effluent Treatment Plant (CETP) • Monitor the water quality • Inspect industries, and Effluent Treatment plants periodically • Inspect the unauthorized industrial discharge and impose penalties	• Central Pollution Control Board • State Industrial Developmental Cooperation • Maharashtra Pollution Control Board • Telangana Pollution Control Board • Andhra Pradesh Pollution Control Board
	Pesticide pollution	Monitor pesticides residues in the Godavari River Organize trainings on IPM at grassroots level	• Central Pollution Control • Maharashtra Pollution Control Board (MPCBs) • Department of Agriculture • Cooperation and Farmers Welfare (DAC&FW) • Ministry of Agriculture
	Sewage pollution	• Monitor the STPs for compliance • Inspect flats, hotels, Sewage Treatment plants periodically	• Maharashtra Pollution Control Board (MPCB) • Maharashtra Municipal Corporations and Councils • Telangana Pollution Control Board • Andhra Pradesh Pollution Control Board
		• Construction of proposed Sewage Treatment Plant (Proposed: 5 MLD +28 MLD)	• Municipal Administration and Urban Development Department, Andhra Pradesh
		• Divert the domestic sewage channels/Nallahs to STPs	• Municipalities in Nashik, Gangakhed city, Nanded district. • Concerned municipalities in Bhadrachalam and East Godavari districts
Pollution abatement	Solid waste pollution	• Dredge out the municipality's solid waste dumping out from the river bank • Install and maintain proper waste disposal infrastructure	• Municipalities in Nashik, Gangakhed city, Nanded district. • Concerned municipalities in Bhadrachalam and East Godavari districts

RESPONSIBLE AUTHORITY	POLICY
PCCF	• The Environment (Protection) Act, 1986 • The Wild Life (Protection) Act, 1972 • The Biological Diversity Act, 2002 • National Forest Policy (1952) • Forest Conservation Act (1980)
Secretary Chief Executive & Director	• The National Fisheries Policy, 2020. • Maharashtra Fisheries Act, 1960 • The Andhra Pradesh Fisheries Act, (1951) • Pradhan Mantri Matsya Sambapa Yojana (Operational Guidelines) 2020
Commissioners/Directors & PCCF	• The Wild Life (Protection) Act, 1972 • The National Fisheries Policy, 2020
Commissioner, Industries, and Commerce, & Head of Department of trade and industries	• Maharashtra Municipal Corporation Act, 1949 • Water (Prevention and Control of Pollution) Act, 1974 • Water (Prevention and Control of Pollution) Cess Act, 1977 • Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016
Chairman	Insecticides Act, 1968
Chairman	• Municipal Solid Wastes (Management and Handling) Rules, 2000 • The Solid Waste Management Rules, 2016 • The Swachh Bharat Mission (Urban and Gramin)
Commissioner and Director	• Environment (Protection) Act, 1986 • Water (Prevention and Control of Pollution) Act, 1974
Mayer & Commissioner	• Environment (Protection) Act, 1986 • Water (Prevention and Control of Pollution) Act, 1974
Mayer & Commissioner	• Environment (Protection) Act, 1986 • Municipal Solid Wastes (Management and Handling) Rules, 2000

RECOMMENDATION		TASK TO BE PERFORMED	IMPLEMENTING AGENCIES
	Plastic waste	Awareness programme on processing segregation and disposal of waste, door-to-door waste collection in urban areas	• Maharashtra, Andhra Pradesh and Telangana Pollution Control Board and Municipal Corporations and Councils
	Biomedical Waste	Implement the BMW Rules, 2016 as amended in all HCF Units. (As per guidelines of CPCB)	• Health Care Facility (HCF) units & Maharashtra Pollution Control Board • Central Pollution Control Board
	E-Waste	Establishment of the facility for disposal of the e-waste	• Maharashtra State Pollution Control Board • Telangana Pollution Control Board • Andhra Pradesh Pollution Control Board
Anthropogenic pressure	Water abstraction	• Check the unauthorized water abstraction • Monitor the quantity of water abstraction • Set scientifically informed limits on the volume of water. • Impose restrictions on unauthorized water abstraction	• Central Water Commission • The Water Resources Department of the concerned states
Awareness		• Awareness of river conservation and its biodiversity • Awareness programs to highlight the issues related to the direct discharge of solid waste, industrial waste, sewage pollution, and open defecation etc.	• Forest Department of Maharashtra, Telangana and Andhra Pradesh • Gram Panchayat, • River Research Centre (RRC) • Nehru Yuva Kendra • Local Self-Government Department

6. Genetic connectivity

i. Establish long-term monitoring programs to track changes in genetic diversity and differentiation over time, especially in the face of environmental changes or anthropogenic impacts and also in the areas influenced by hatcheries.

ii. Fish ladders and bypass systems should be implemented in dams to allow fish migration and gene flow.

iii. Creating and maintaining habitat corridors to enhance genetic diversity by enabling interbreeding between populations.

iv. Set and enforce size limits on commercial fishes to be harvested to allow them to reach maturity and contribute to breeding.

v. Improve ecosystem resilience by allowing species to access larger areas for food, mating, and shelter.

vi. Protect and restore migration routes, such as rivers and coastal areas, to enable fish populations to interbreed and maintain genetic diversity across regions

7. Awareness

Community awareness on the importance of the river ecosystem will be very crucial for its proper conservation. Therefore, regular organization of awareness campaigns such as street plays, awareness camps, signboards, pamphlets, holding competitions, quizzes and fairs in schools, colleges, and villages should be conducted to educate the public about the importance of river conservation. This will

RESPONSIBLE AUTHORITY	POLICY
Head, Pollution Control Board Maharashtra, Andhra Pradesh and Telangana	• Environment (Protection) Act, 1986 • Municipal Solid Wastes (Management and Handling) Rules, 2000 • Single-use Plastic (Regulation) Act, 2022
Head, Pollution Control Board Maharashtra, Andhra Pradesh and Telangana	• Environment (Protection) Act, 1986 • Biomedical Waste Management Rules, 2016
Head, Pollution Control Board of Maharashtra, Andhra Pradesh and Telangana	• Environment (Protection) Act, 1986 • E-Waste (Management) Rules, 2016
Head, Water Resource Department of the concerned states	• The Rivers and Canals Act, 1863 • The Minimum Water Flow Protection Act, 1977
PCCF Directorate of Fisheries District Administration	• Water (Prevention and Control of Pollution) Act, 1974 • National River Conservation Plan (NRCP), 1995

ensure people's participation in Godavari River management and conservation.

i. Concerned river rejuvenation committees of the respective states should create amusement parks along the Godavari River stretches to connect people with the Godavari River and river festivals should be conducted to create awareness among the public

ii. Nehru Yuva Kendra should make a campaign viz., public awareness through Visuals, Nukkad Natak's, short movies, etc. regarding river conservation.

iii. The forest department should install awareness boards within the 500-meter buffer area on both the banks to sensitize local communities about Godavari River biodiversity and threats.

iv. The local self-government Department should install boards regarding cleanliness within a 500 m buffer of the Godavari River.

v. Concerned municipalities of each district are recommended to create an awareness room during the duration of religious festivals and Mela's to spread awareness about the harmful impacts of the emersion of idols, Nirmalya, etc in the river.

14

APPENDICES

Appendix 2.1: Status of dams in the Godavari River.

Name of Dams	River	Type of Dam	Year of Completion	Catchment Area (km^2)	Dam Length (m)	Gross Storage Capacity (MCM)	Live Storage Capacity (MCM)	Submergence Area(ha)	Purpose
Bandlavagu, Kukkalgudur	Godavari	Earthen			1121	8.93	7.59		IR
Boath	Godavari	Earthen	2004		1445	5.31	4.88		IR
Gangapur	Godavari	Earthen	1965	357.4	3902	215.88	203.88	2231	HE, IR
Gujjulavagu, Gandhari	Godavari	Earthen	1998		780	3.26	2.777		IR
Jayakwadi- I	Godavari	Earthen	1976	21750	10415	2909	2170	39761	HE, IR
Kuppakanti, Kuppakal (V)	Godavari	Earthen/ Gravity/ Masonry	1999		1040	1.95	1.7		IR
Large, Adloor Yallareddy	Godavari	Earthen	1901		1959	3.51	2.98		IR
Large, Bibipet	Godavari	Earthen	1911			4.01	3.41		IR
Large, Brahmanpaly	Godavari	Earthen			2500	3.2	2.88		IR
Large, Dharmaraopet	Godavari	Earthen	1928		930	1.09	0.93		IR
Large, Garepally (V)	Godavari	Earthen			1089	8.04	6.81		IR
Large, Indalwai (V)	Godavari	Earthen			1400	3.95	3.35		IR
Large, Jangampally	Godavari	Earthen	1898		1110	1.72	1.46		IR
Large, Kachapur	Godavari	Earthen	1896		1260	4.12	3.5		IR
Large, Kamareddy	Godavari	Earthen	1897		1890	4.97	4.22		IR
Large, Kapuram (V)	Godavari	Earthen			780	1.42	1.13		IR
Large, Khajar (V)	Godavari	Earthen			1920	7.13	6		IR
Large, Manchippa (V)	Godavari	Earthen			1000	9.52	8		IR
Large, Pedallareddy	Godavari	Earthen	1892						IR
Large, Pulkal	Godavari	Earthen	1918		1020	2.5	2.13		IR
Large, Sultanabad (V&M)	Godavari	Earthen			1574	4.2	3.82		IR
Large, Uppalwai	Godavari	Earthen	1918		1140	1.08	0.92		IR
Medi Cheru, Adavi Srirampur (V)	Godavari	Earthen			2031	2.23	1.89		IR
Oora Cheru, Yadaram	Godavari	Earthen	1953		1560	1.47	1.25		IR
Pedda Cheru, Ameenpur	Godavari	Earthen	1912		660	2.66	2.26		IR
Sriram Sagar/ Pochampad	Godavari	Earthen/ Gravity/ Masonry	1977	91751	15600	3172	2555		HE, IR

(IR: Irrigation, HE: Hydro-electric)

Appendix 5.1: Volume equation and specific gravity for tree species recorded in the riverine zone of Godavari River

Tree Species	Volume Equation	Species-specific gravity
Acacia catechu (L.f.) Willd.	V =-0.02471 + 0.16897 D + 1.12083 D2 + 2.9328 D3	0.76
Acacia nilotica (L.) Delile	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.76
Aegle marmelos (L.) Corrêa	V/D2=0.0697/D2-1.4597/D+11.79933-2.35397D	0.754
Ailanthus excelsa Roxb.	?V=-0.41331+2.66051D+0.94576?D	0.35
Albizia lebbeck (L.) Benth.	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.76
Albizia odoratissima (L.f.) Benth.	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.76
Annona reticulata L.	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.76
Artocarpus heterophyllus Lam.	?V = ?0.15154+2.79983D	0.45
Azadirachta indica A.Juss.	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.76
Balanites aegyptiaca (L.) Delile	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.76
Balanites glabra Mildbr. & Schltr.	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.76
Balanites roxburghii Planch.	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.76
Barringtonia acutangula (L.) Gaertn.	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.61
Bombax ceiba L.	V/D2=0.04507/D2-0.93461/D+5.48513+9.16037D	0.329
Borassus flabellifer L.	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.76
Bridelia retusa (L.) A.Juss.	?V=0.1162+4.12711D-1.08505?D	0.76
Butea monosperma (Lam.) Taub.	?V=-0.24276+2.955255D	0.74
Capparis divaricata Lam.	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.76
Cassia javanica L.	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.76
Cocos nucifera L.	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.76
Cordia dentata Poir.	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.76
Cordia dichotoma G.Forst.	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.76
Cordia myxa L.	V=0.49388+7.56417D-31.45373D2+50.93877D3	0.61
Cordia sinensis Lam.	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.76
Dalbergia sissoo DC.	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.76
Delonix regia (Bojer ex Hook.) Raf.	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.76
Diospyros melanoxylon Roxb.	V=0.01456+0.32613D2H	0.678
Eucalyptus grandis L'Hér.	V=0.02894-0.89284D+8.72416D2	0.603
Ficus benghalensis Roxb.	?V = 0.03629+3.95389D?0.84421 ?D	0.39
Ficus hispida L.f.	exp[-0.37+0.33*ln(DBH)+0.933*ln(D- BH)2-0.122*ln(DBH)3]	0.76
Ficus mollis Vahl	?V = 0.03629+3.95389D?0.84421 ?D	0.39
Ficus racemosa L.	?V = 0.03629+3.95389D?0.84421 ?D	0.39
Ficus religiosa L.	?V = 0.03629+3.95389D?0.84421 ?D	0.385
Haldina cordifolia (Roxb.) Ridsdale	V=-0.060564-1.509868D	0.78

Tree Species	Volume Equation	Species-specific gravity
Holoptelea integrifolia (Roxb.) Planch.	V/D2=0.0697/D2-1.4597/D+11.79933-2.35397D	0.592
Leucaena leucocephala (Lam.) de Wit	exp[-0.37+0.33*In(DBH)+0.933*In(D- BH)2-0.122*In(DBH)3]	0.76
Limonia acidissima Groff	exp[-0.37+0.33*In(DBH)+0.933*In(D- BH)2-0.122*In(DBH)3]	0.76
Mallotus philippensis (Lam.) Müll.Arg.	V=0.14749-2.87503D+19.61977D2-19.11630D3	0.88
Mangifera indica L.	exp[-0.37+0.33*In(DBH)+0.933*In(D- BH)2-0.122*In(DBH)3]	0.588
Mitragyna parvifolia (Roxb.) Korth.	V/D2=0.099768/D2-1.744274/D+10.086934	0.558
Moringa oleifera Lam.	exp[-0.37+0.33*In(DBH)+0.933*In(D- BH)2-0.122*In(DBH)3]	0.76
Parkinsonia aculeata L.	exp[-0.37+0.33*In(DBH)+0.933*In(D- BH)2-0.122*In(DBH)3]	0.76
Peltophorum pterocarpum (DC.) K.Heyne	V/D=-0.018208/D-0.145889+5.03522D+5.91151D2	0.55
Phoenix sylvestris (L.) Roxb.	exp[-0.37+0.33*In(DBH)+0.933*In(D- BH)2-0.122*In(DBH)3]	0.76
Phyllanthus emblica L.	V=0.022635+4.889163D2	0.66
Pithecellobium dulce (Roxb.) Benth.	exp[-0.37+0.33*In(DBH)+0.933*In(D- BH)2-0.122*In(DBH)3]	0.76
Pongamia pinnata (L.) Pierre	exp[-0.37+0.33*In(DBH)+0.933*In(D- BH)2-0.122*In(DBH)3]	0.76
Prosopis juliflora (Sw.) DC.	V =0.081467-1.063661 D + 6.452918 D2	0.7
Putranjiva roxburghii Wall.	exp[-0.37+0.33*In(DBH)+0.933*In(D- BH)2-0.122*In(DBH)3]	0.61
Samanea saman (Jacq.) Merr.	exp[-0.37+0.33*In(DBH)+0.933*In(D- BH)2-0.122*In(DBH)3]	0.76
Sapindus mukorossi Gaertn.	exp[-0.37+0.33*In(DBH)+0.933*In(D- BH)2-0.122*In(DBH)3]	0.76
Senna siamea (Lam.) H.S.Irwin & Barneby	exp[-0.37+0.33*In(DBH)+0.933*In(D- BH)2-0.122*In(DBH)3]	0.76
Sesbania sesban (L.) Merr.	exp[-0.37+0.33*In(DBH)+0.933*In(D- BH)2-0.122*In(DBH)3]	0.76
Spondias indica Willd.	?V =0.4987+6.18662D-2.95076?D	0.61
Sterculia urens Roxb.	V = 0.27909?3.26515D+13.46829D2	0.543
Syzygium cumini (L.) Skeels	?V=-0.5923+2.33654D	0.647
Tamarindus indica L.	exp[-0.37+0.33*In(DBH)+0.933*In(D- BH)2-0.122*In(DBH)3]	0.61
Tectona grandis L.f.	V=0.01103+0.31458D2H	0.72
Terminalia arjuna (Roxb. ex DC.) Wight & Arn.	V=0.50603-6.64203D+25.23882D2-9.19797D3	0.628
Terminalia elliptica Willd.	V=0.05061-1.11994D+8.77839D2	0.686
Terminalia pallida Brandis	exp[-0.37+0.33*In(DBH)+0.933*In(D- BH)2-0.122*In(DBH)3]	0.76
Trewia nudiflora L.	?V=-0.45312-0.41426D+2.10913?D	0.76
Vachellia farnesiana (L.) Wight & Arn.	exp[-0.37+0.33*In(DBH)+0.933*In(D- BH)2-0.122*In(DBH)3]	0.76
Ziziphus mauritiana Lam.	V/D2=0.0697/D2-1.4597/D+11.79933-2.35397D	0.597

Appendix. 5.2: Checklist of tree species recorded in the riparian zone of the Godavari River

Order	Family	Scientific Name	Habit	Habitat	Nativity	Nature	IUCN	Zone
Fabales	Mimosaceae	*Acacia catechu* (L.f.) Willd.	Tree	Terrestrial	Native	Perennial	LC	UZ, MZ, LZ
Fabales	Mimosaceae	*Acacia nilotica* (L.) Delile	Tree	Terrestrial	Native	Perennial	LC	UZ, MZ, LZ
Sapindales	Rutaceae	*Aegle marmelos* (L.) Corrêa	Tree	Terrestrial	Native	Perennial	NT	UZ
Sapindales	Simaroubaceae	*Ailanthus excelsa* Roxb.	Tree	Terrestrial	Native	Perennial	NE	UZ
Fabales	Fabaceae	*Albizia lebbeck* (L.) Benth.	Tree	Terrestrial	Native	Perennial	LC	UZ
Fabales	Fabaceae	*Albizia odoratissima* (L.f.) Benth.	Tree	Terrestrial	Native	Perennial	LC	MZ
Magnoliales	Annonaceae	*Annona reticulata* L.	Tree	Terrestrial	Exotic	Perennial	NE	UZ
Rosales	Moraceae	*Artocarpus heterophyllus* Lam.	Tree	Terrestrial	Native	Perennial	NE	LZ
Sapindales	Meliaceae	*Azadirachta indica* A.Juss.	Tree	Terrestrial	Native	Perennial	LC	UZ, MZ, LZ
Zygophyllales	Zygophyllaceae	*Balanites aegyptiaca* (L.) Delile	Tree	Terrestrial	Native	Perennial	LC	UZ
Zygophyllales	Zygophyllaceae	*Balanites glabra* Mildbr. & Schltr.	Tree	Terrestrial	Native	Perennial	LC	UZ
Zygophyllales	Zygophyllaceae	*Balanites roxburghii* Planch.	Tree	Terrestrial	Native	Perennial	LC	UZ
Ericales	Lecythidaceae	*Barringtonia acutangula* (L.) Gaertn.	Tree	Terrestrial	Native	Perennial	LC	LZ
Malvales	Malvaceae	*Bombax ceiba* L.	Tree	Terrestrial	Native	Perennial	NE	UZ, LZ
Arecales	Arecaceae	*Borassus flabellifer* L.	Tree	Terrestrial	Exotic	Perennial	LC	MZ, LZ
Malpighiales	Phyllanthaceae	*Bridelia retusa* (L.) A.Juss.	Tree	Terrestrial	Native	Perennial	LC	LZ
Fabales	Fabaceae	*Butea monosperma* (Lam.) Taub.	Tree	Terrestrial	Native	Perennial	LC	MZ, LZ
Brassicales	Capparaceae	*Capparis divaricata* Lam.	Tree	Terrestrial	Native	Perennial	NE	UZ
Fabales	Fabaceae	*Cassia javanica* L.	Tree	Terrestrial	Exotic	Perennial	NE	UZ
Arecales	Arecaceae	*Cocos nucifera* L.	Tree	Terrestrial	Native	Perennial	NE	LZ
Boraginales	Boraginaceae	*Cordia dentata* Poir.	Tree	Terrestrial	Native	Perennial	NE	UZ
Boraginales	Boraginaceae	*Cordia dichotoma* G.Forst.	Tree	Terrestrial	Native	Perennial	LC	UZ
Boraginales	Boraginaceae	*Cordia myxa* L.	Tree	Terrestrial	Native	Perennial	LC	UZ, LZ
Boraginales	Boraginaceae	*Cordia sinensis* Lam.	Tree	Terrestrial	Native	Perennial	LC	UZ
Fabales	Fabaceae	*Dalbergia sissoo* DC.	Tree	Terrestrial	Native	Perennial	LC	UZ
Fabales	Fabaceae	*Delonix regia* (Hook.) Raf.	Tree	Terrestrial	Exotic	Perennial	LC	UZ
Ericales	Ebenaceae	*Diospyros melanoxylon* Roxb.	Tree	Terrestrial	Native	Perennial	LC	UZ, LZ
Myrtales	Myrtaceae	*Eucalyptus grandis* W.Hill	Tree	Terrestrial	Exotic	Perennial	LC	UZ, LZ
Rosales	Moraceae	*Ficus Benghalensis* L	Tree	Terrestrial	Native	Perennial	LC	UZ
Rosales	Moraceae	*Ficus hispida* L.f.	Tree	Terrestrial	Native	Perennial	LC	UZ
Rosales	Moraceae	*Ficus mollis* Vahl	Tree	Terrestrial	Native	Perennial	LC	LZ
Rosales	Moraceae	*Ficus racemosa* L.	Tree	Terrestrial	Native	Perennial	LC	UZ, MZ, LZ
Rosales	Moraceae	*Ficus religiosa* L.	Tree	Terrestrial	Native	Perennial	LC	UZ
Gentianales	Rubiaceae	*Haldina cordifolia* (Roxb.) Ridsdale	Tree	Terrestrial	Native	Perennial	NE	LZ

Order	Family	Scientific Name	Habit	Habitat	Nativity	Nature	IUCN	Zone
Rosales	Ulmaceae	*Holoptelea integrifolia* (Roxb.) Planch.	Tree	Terrestrial	Native	Perennial	NE	LZ
Fabales	Mimosaceae	*Leucaena leucocephala* (Lam.) de Wit	Tree	Terrestrial	Native	Perennial	NE	UZ, LZ
Sapindales	Rutaceae	*Limonia acidissima* L.	Tree	Terrestrial	Native	Perennial	NE	UZ, MZ
Malpighiales	Euphorbiaceae	*Mallotus philippensis* (Lam.) Müll.Arg.	Tree	Terrestrial	Native	Perennial	LC	LZ
Sapindales	Anacardiaceae	*Mangifera indica* L.	Tree	Terrestrial	Native	Perennial	DD	UZ, LZ
Gentianales	Rubiaceae	*Mitragyna parvifolia* (Roxb.) Korth.	Tree	Terrestrial	Native	Perennial	NE	LZ
Capparales	Moringaceae	*Moringa oleifera* Lam.	Tree	Terrestrial	Native	Perennial	LC	UZ, LZ
Fabales	Fabaceae	*Parkinsonia aculeata* L.	Tree	Terrestrial	Exotic	Perennial	LC	UZ
Fabales	Caesalpiniaceae	*Peltophorum pterocarpum* (DC.) K.Heyne	Tree	Terrestrial	Native	Perennial	NE	LZ
Arecales	Arecaceae	*Phoenix sylvestris* (L.) Roxb.	Tree	Terrestrial	Native	Perennial	NE	MZ
Malpighiales	Phyllanthaceae	*Phyllanthus emblica* L.	Tree	Terrestrial	Native	Perennial	LC	LZ
Fabales	Mimosaceae	*Pithecellobium dulce* (Roxb.) Benth.	Tree	Terrestrial	Native	Perennial	LC	UZ, MZ, LZ
Fabales	Fabaceae	*Pongamia pinnata* (L.) Pierre	Tree	Terrestrial	Native	Perennial	LC	UZ, MZ, LZ
Fabales	Mimosaceae	*Prosopis juliflora* (Sw.) DC.	Tree	Terrestrial	Native	Perennial	LC	UZ, MZ, LZ
Malpighiales	Putranjivaceae	*Putranjiva roxburghii* Wall.	Tree	Terrestrial	Native	Perennial	LC	LZ
Fabales	Fabaceae	*Samanea saman* (Jacq.) Merr.	Tree	Terrestrial	Exotic	Perennial	LC	UZ
Sapindales	Sapindaceae	*Sapindus mukorossi* Gaertn.	Tree	Terrestrial	Native	Perennial	LC	LZ
Fabales	Fabaceae	*Senna siamea* (Lam.) H.S.Irwin & Barneby	Tree	Terrestrial	Exotic	Perennial	LC	UZ
Fabales	Fabaceae	*Sesbania sesban* (L.) Merr.	Tree	Terrestrial	Native	Perennial	LC	UZ
Sapindales	Anacardiaceae	*Spondias indica* (Willd.) M.R.Almeida	Tree	Terrestrial	Native	Perennial	NE	LZ
Malvales	Malvaceae	*Sterculia urens* Roxb.	Tree	Terrestrial	Native	Perennial	NE	UZ
Malvales	Malvaceae	*Syzygium cumini* (L.) Skeels	Tree	Terrestrial	Native	Perennial	NE	UZ, LZ
Fabales	Caesalpiniaceae	*Tamarindus indica* L.	Tree	Terrestrial	Native	Perennial	LC	UZ, LZ
Lamiales	Verbenaceae	*Tectona grandis* L.f.	Tree	Terrestrial	Native	Perennial	LC	UZ, MZ, LZ
Myrtales	Combretaceae	*Terminalia arjuna* (Roxb. ex DC.) Wight & Arn.	Tree	Terrestrial	Native	Perennial	LC	MZ
Myrtales	Combretaceae	*Terminalia elliptica* Willd.	Tree	Terrestrial	Native	Perennial	LC	UZ, MZ, LZ
Myrtales	Combretaceae	*Terminalia pallida* Brandis	Tree	Terrestrial	Native	Perennial	VU	UZ
Malpighiales	Euphorbiaceae	*Trewia nudiflora* L.	Tree	Terrestrial	Native	Perennial	LC	LZ
Fabales	Fabaceae	*Vachellia farnesiana* (L.) Wight & Arn.	Tree	Terrestrial	Exotic	Perennial	LC	UZ
Rhamnales	Rhamnaceae	*Ziziphus mauritiana* Lam.	Tree	Terrestrial	Native	Perennial	LC	UZ, LZ

Appendix 5.3. Checklist of Shrub Species recorded in the riparian zone of the Godavari River

Order	Family	Scientific Name	Habit	Habitat	Nativity	Nature	IUCN	Zone
Fabales	Fabaceae	*Alantsilodendron pilosum* (Willd.) Britton & Rose	Shrubs	Terrestrial	Native	Perennial	LC	LZ
Gentianales	Apocynaceae	*Calotropis procera* (Aiton) W.T.Aiton	Shrubs	Terrestrial	Native	Perennial	NE	UZ, MZ, LZ
Brassicales	Capparaceae	*Capparis sepiaria* L.	Shrubs	Terrestrial	Native	Perennial	LC	UZ, MZ
Lamiales	Lamiaceae	*Clerodendrum phlomidis* L.f.	Shrubs	Terrestrial	Native	Perennial	LC	UZ, MZ
Solanales	Solanaceae	*Datura metel* L.	Shrubs	Terrestrial	Native	Annual	NE	UZ, LZ
Fabales	Fabaceae	*Guilandina bonduc* L.	Shrubs	Terrestrial	Native	Perennial	LC	LZ
Malvales	Malvaceae	*Helicteres isora* L.	Shrubs	Terrestrial	Native	Perennial	NE	LZ
Fabales	Fabaceae	*Indigofera tinctoria* L.	Shrubs	Terrestrial	Exotic	Perennial	LC	UZ
Solananles	Convolvulaceae	*Ipomoea carnea* Jacq.	Shrubs	Terrestrial	Exotic	Annual	NE	UZ
Malpighiales	Euphorbiaceae	*Jatropha curcas* L.	Shrubs	Terrestrial	Exotic	Perennial	NE	UZ
Malpighiales	Euphorbiaceae	*Jatropha gossypiifolia* L.	Shrubs	Terrestrial	Native	Perennial	LC	UZ, MZ
Lamiales	Verbenaceae	*Lantana camara* L.	Shrubs	Terrestrial	Exotic	Perennial	NE	UZ, MZ, LZ
Malpighiales	Phyllanthaceae	*Phyllanthus reticulatus* Poir.	Shrubs	Terrestrial	Native	Perennial	LC	UZ, MZ, LZ
Malpighiales	Euphorbiaceae	*Ricinus communis* L.	Shrubs	Terrestrial	Native	Perennial	NE	UZ
Fabales	Fabaceae	*Senna auriculata* (L.) Roxb.	Shrubs	Terrestrial	Native	Perennial	NE	UZ, MZ, LZ
Solananles	Solanaceae	*Solanum torvum* Sw.	Shrubs	Terrestrial	Exotic	Perennial	NE	UZ
Lamiales	Lamiaceae	*Vitex negundo* L.	Shrubs	Terrestrial	Native	Perennial	LC	UZ, MZ, LZ
Sonales	Solanaceae	*Withania somnifera* (L.) Dunal	Shrubs	Terrestrial	Native	Perennial	NE	UZ
Myrtales	Lythraceae	*Woodfordia fruticosa* (L.) Kurz	Shrubs	Terrestrial	Native	Perennial	NE	UZ, LZ
Rosales	Rhamnaceae	*Ziziphus nummularia* (Burm.f.) Wight & Arn.	Shrubs	Terrestrial	Native	Perennial	NE	UZ

NE: Not evaluated, LC: Least concern, UZ: Upper zone, MZ: Middle Zone, LZ: Lower Zone

Appendix 5.4. Checklist of Herb Species recorded in the riparian zone of the Godavari River

Order	Family	Scientific Name	Habit	Habitat	Nativity	Nature	IUCN	Zone
Malvales	Malvaceae	*Abutilon grandifolium* (Willd.) Sweet	Herb	Terrestrial	Native	Annual	NE	UZ, MZ, LZ
Malvales	Malvaceae	*Abutilon indicum* (L.) Sweet	Herb	Terrestrial	Native	Annual	NE	UZ, MZ, LZ
Malpighiales	Euphorbiaceae	*Acalypha indica* L.	Herb	Terrestrial	Native	Annual	NE	UZ
Caryophyllales	Amaranthaceae	*Achyranthes aspera* L.	Herb	Terrestrial	Native	Perennial	NE	UZ, MZ, LZ
Asterales	Asteraceae	*Acmella paniculata* (Wall. ex DC.) R.K.Jansen	Herb	Terrestrial	Exotic	Annual	NE	UZ, LZ
Asterales	Asteraceae	*Acmella radicans* (Jacq.) R.K.Jansen	Herb	Terrestrial	Exotic	Annual	NE	UZ
Caryophyllales	Amaranthaceae	*Aerva lanata* (L.) Juss. ex Schult.	Herb	Terrestrial	Native	Perennial	NE	MZ, LZ
Asterales	Asteraceae	*Ageratum conyzoides* L.	Herb	Terrestrial	Exotic	Annual	LC	UZ, MZ, LZ
Caryophyllales	Amaranthaceae	*Alternanthera paronychioides* A.St.-Hil.	Herb	Terrestrial	Exotic	Perennial	NE	UZ
Caryophyllales	Amaranthaceae	*Alternanthera philoxeroides* (Mart.) Griseb.	Herb	Aquatic	Native	Perennial	LC	UZ, LZ
Caryophyllales	Amaranthaceae	*Alternanthera sessilis* (L.) R.Br. ex DC.	Herb	Aquatic	Native	Perennial	LC	UZ, MZ, LZ
Caryophyllales	Amaranthaceae	*Amaranthus spinosus* L.	Herb	Terrestrial	Exotic	Annual	LC	UZ
Caryophyllales	Amaranthaceae	*Amaranthus viridis* L.	Herb	Terrestrial	Native	Annual	NE	UZ, MZ
Myrtales	Lythraceae	*Ammannia baccifera* L.	Herb	Terrestrial	Native	Annual	LC	LZ
Ranunculales	Papaveraceae	*Argemone mexicana* L.	Herb	Terrestrial	Exotic	Perennial	NE	UZ, MZ, LZ
Malvales	Malvaceae	*Azanza lampas* (Cav.) Alef.	Herb	Terrestrial	Native	Perennial	NE	LZ
Lamiales	Plantaginaceae	*Bacopa monnieri* (L.) Wettst.	Herb	Terrestrial	Native	Perennial	LC	UZ
Asterales	Asteraceae	*Blumea eriantha* DC.	Herb	Terrestrial	Native	Annual	NE	MZ, LZ
Caryophyllales	Nyctaginaceae	*Boerhaavia diffusa* L.	Herb	Terrestrial	Native	Perennial	NE	LZ
Caryophyllales	Nyctaginaceae	*Boerhavia erecta* L.	Herb	Terrestrial	Exotic	Perennial	NE	UZ
Gentianales	Gentianaceae	*Canscora diffusa* (Vahl) R.Br. ex Roem. & Schult.	Herb	Terrestrial	Native	Annual	NE	UZ
Gentianales	Gentianaceae	*Celosia argentea* L.	Herb	Terrestrial	Native	Annual	NE	UZ, MZ, LZ
Caryophyllales	Amaranthaceae	*Chenopodium album* L.	Herb	Terrestrial	Native	Annual	NE	UZ
Asterales	Asteraceae	*Chromolaena odorata* (L.) R.M.King & H.Rob.	Herb	Terrestrial	Exotic	Annual	NE	UZ, MZ, LZ
Malpighiales	Euphorbiaceae	*Chrozophora rottleri* (Geiseler) A.Juss. ex Spreng	Herb	Terrestrial	Native	Annual	NE	UZ, MZ, LZ
Malpighiales	Euphorbiaceae	*Chrozophora tinctoria* (L.) Raf.	Herb	Terrestrial	Exotic	Perennial	NE	UZ
Brassicales	Cleomaceae	*Cleome chelidonii* L.f.	Herb	Terrestrial	Native	Perennial	NE	UZ

Order	Family	Scientific Name	Habit	Habitat	Nativity	Nature	IUCN	Zone
Brassicales	Cleomaceae	*Cleome viscosa* L.	Herb	Terrestrial	Native	Annual	NE	UZ, LZ
Boraginales	Boraginaceae	*Coldenia procumbens* L.	Herb	Aquatic	Native	Annual	LC	UZ, LZ
Alismatales	Araceae	*Colocasia esculenta* (L.) Schott	Herb	Aquatic	Native	Perennial	NE	UZ
Commelinales	Commelinaceae	*Commelina benghalensis* L.	Herb	Terrestrial	Native	Perennial	LC	UZ, MZ
Asterales	Asteraceae	*Cosmos caudatus* Kunth	Herb	Terrestrial	Exotic	Annual	NE	UZ
Malpighiales	Euphorbiaceae	*Croton bonplandianus* Baill.	Herb	Terrestrial	Exotic	Annual	NE	UZ, MZ, LZ
Asterales	Asteraceae	*Cyanthillium cinereum* (L.) H.Rob.	Herb	Terrestrial	Native	Perennial	NE	UZ, MZ, LZ
Asterales	Asteraceae	*Cyathocline purpurea* (Buch. Ham. ex D.Don) Kuntze	Herb	Terrestrial	Native	Annual	LC	UZ, LZ
Caryophyllales	Amaranthaceae	*Deeringia spicata* (Thunb.) Moq.	Herb	Terrestrial	Native	Perennial	NE	UZ
Fabales	Fabaceae	*Desmanthus virgatus* (L.) Willd.	Herb	Terrestrial	Exotic	Perennial	LC	UZ
Caryophyllales	Amaranthaceae	*Digera muricata* (L.) Mart.	Herb	Terrestrial	Native	Perennial	NE	UZ, MZ, LZ
Lamiales	Amaranthaceae	*Dipteracanthus prostratus* (Poir.) Nees	Herb	Terrestrial	Native	Annual	NE	MZ, LZ
Lamiales	Acanthaceae	*Ecbolium ligustrinum* (Vahl) Vollesen	Herb	Terrestrial	Native	Annual	NE	UZ
Asterales	Asteraceae	*Erigeron acris* L.	Herb	Terrestrial	Exotic	Perennial	LC	UZ
Asterales	Asteraceae	*Erigeron trilobus* (Decne.) Kuntze	Herb	Terrestrial	Exotic	Annual	NE	UZ
Malpighiales	Euphorbiaceae	*Euphorbia hirta* L.	Herb	terrestrial	Exotic	Perennial	NE	UZ, MZ, LZ
Malpighiales	Euphorbiaceae	*Euphorbia serpens* Kunth	Herb	Terrestrial	Exotic	Perennial	NE	UZ
Boraginales	Boraginaceae	*Euploca ovalifolia* (Forssk.) Diane & Hilger	Herb	Terrestrial	Native	Annual	NE	UZ
Fabales	Fabaceae	*Flemingia strobilifera* (L.) W.T.Aiton	Herb	Terrestrial	Native	Perennial	NE	UZ, LZ
Asterales	Asteraceae	*Grangea maderaspatana* (L.) Poir.	Herb	Terrestrial	Native	Annual	NE	LZ
Boraginales	Boraginaceae	*Heliotropium europaeum* L.	Herb	Terrestrial	Native	Annual	NE	LZ
Lamiales	Acanthaceae	*Hemigraphis latebrosa* (Rottler ex Vahl) Hallier f.	Herb	Terrestrial	Native	Annual	NE	UZ, MZ, LZ
Malvales	Malvaceae	*Hibiscus flabelliformis* Dalzell	Herb	Terrestrial	Native	Perennial	NE	UZ
Lamiales	Acanthaceae	*Hygrophila auriculata* (Schumach.) Heine	Herb	Terrestrial	Native	Annual	LC	UZ
Asterales	Asteraceae	*Laggera crispata* (Vahl) Hepper & Wood	Herb	Terrestrial	Native	Perennial	NE	UZ

Order	Family	Scientific Name	Habit	Habitat	Nativity	Nature	IUCN	Zone
Asterales	Asteraceae	*Launaea nudicaulis* (L.) Hook.f.	Herb	Terrestrial	Native	Annual	NE	UZ
Lamiales	Lamiaceae	*Leonotis nepetifolia* (L.) R.Br.	Herb	Terrestrial	Exotic	Perennial	NE	UZ, MZ
Lamiales	Verbenaceae	*Lippia alba* (Mill.) N.E.Br. ex Britton & P.Wilson	Herb	terrestrial	Exotic	Perennial	NE	LZ
Malvales	Malvaceae	*Malvastrum coromandelianum* (L.) Garcke	Herb	Terrestrial	Native	Perennial	NE	UZ, MZ
Fabales	Fabaceae	*Melilotus albus* Medik.	Herb	Terrestrial	Native	Annual	NE	LZ
Lamiales	Lamiaceae	*Mesosphaerum suaveolens* (L.) Kuntze	Herb	terrestrial	Exotic	Annual	NE	UZ, MZ, LZ
Gentianales	Rubiaceae	*Mitracarpus hirtus* (L.) DC.	Herb	Terrestrial	Native	Annual	NE	UZ
Lamiales	Lamiaceae	*Nicoteba betonica* (L.) Brummitt	Herb	Terrestrial	Native	Perennial	NE	UZ
Lamiaceae	Lamiales	*Ocimum africanum* Lour.	Herb	Terrestrial	Exotic	Perennial	NE	MZ
Lamiaceae	Lamiales	*Ocimum basilicum* L.	Herb	Terrestrial	Native	Perennial	NE	LZ
Lamiaceae	Lamiales	*Ocimum tenuiflorum* L.	Herb	Terrestrial	Native	Perennial	NE	UZ, MZ, LZ
Lamiales	Lamiaceae	*Orthosiphon parvifolius* Vatke	Herb	Terrestrial	Native	Perennial	NE	UZ
Asterales	Asteraceae	*Parthenium hysterophorus* L.	Herb	Terrestrial	Exotic	Annual	NE	UZ, MZ, LZ
Lamiales	Acanthaceae	*Peristrophe paniculata* (Forssk.) Brummitt	Herb	Terrestrial	Native	Annual	NE	UZ, MZ, LZ
Caryophyllales	Polygonaceae	*Persicaria glabra* (Willd.) M.Gómez	Herb	Aquatic	Native	Annual	NE	UZ, MZ
Fabales	Fabaceae	*Phaseolus vulgaris* L.	Herb	Terrestrial	Exotic	Annual	LC	UZ
Lamiales	Verbenaceae	*Phyla nodiflora* (L.) Greene	Herb	Terrestrial	Native	Perennial	NE	UZ
Malpighiales	Phyllanthaceae	*Phyllanthus niruri* L.	Herb	terrestrial	Native	Annual	NE	UZ, LZ
Alismatales	Araceae	*Pistia stratiotes* L.	Herb	Aquatic	Exotic	Perennial	LC	UZ
Commelinales	Pontederiaceae	*Pontederia crassipes* Mart.	Herb	Aquatic	Exotic	Perennial	LC	UZ
Caryophyllales	Portulacaceae	*Portulaca oleracea* L.	Herb	Terrestrial	Exotic	Annual	LC	UZ, LZ
Fabales	Fabaceae	*Psoralea corylifolia* L.	Herb	Terrestrial	Native	Annual	LC	UZ, MZ, LZ
Asterales	Asteraceae	*Pulicaria arabica* (L.) Cass.	Herb	Terrestrial	Native	Annual	NE	UZ
Lamiales	Acanthaceae	*Ruellia prostrata* Poir.	Herb	terrestrial	Native	Perennial	NE	UZ, LZ
Caryophyllales	Polygonaceae	*Rumex palustris* Sm.	Herb	Terrestrial	Exotic	Perennial	NE	UZ
Lamiales	Acanthaceae	*Rungia pectinata* (L.) Nees	Herb	Terrestrial	Native	Annual	NE	UZ, MZ, LZ
Fabales	Fabaceae	*Senna obtusifolia* (L.) H.S.Irwin & Barneby	Herb	Terrestrial	Exotic	Perennial	LC	UZ
Fabales	Caesalpinaceae	*Senna occidentalis* (L.) Link	Herb	Terrestrial	Exotic	Annual	LC	LZ
Fabales	Fabaceae	*Senna tora* (L.) Roxb.	Herb	Terrestrial	Exotic	Annual	NE	UZ, MZ, LZ

Order	Family	Scientific Name	Habit	Habitat	Nativity	Nature	IUCN	Zone
Lamiales	Pedaliaceae	*Sesamum indicum* L.	Herb	terrestrial	Native	Annual	NE	UZ, LZ
Malvales	Malvaceae	*Sida acuta* Burm.f.	Herb	Terrestrial	Native	Annual	NE	UZ, MZ, LZ
Malvales	Malvaceae	*Sida cordifolia* L.	Herb	Terrestrial	Native	Annual	NE	UZ, MZ, LZ
Malvales	Malvaceae	*Sida rhombifolia* L.	Herb	Terrestrial	Native	Annual	NE	UZ, MZ, LZ
Solanales	Solanaceae	*Solanum chenopodioides* Lam.	Herb	Terrestrial	Exotic	Annual	NE	UZ
Solanales	Solanaceae	*Solanum nigrum* L.	Herb	Terrestrial	Native	Annual	NE	UZ, LZ
Solanales	Solanaceae	*Solanum virginianum* L.	Herb	Terrestrial	Native	Annual	NE	UZ, MZ, LZ
Asterales	Asteraceae	*Sonchus oleraceus* L.	Herb	Terrestrial	Exotic	Annual	NE	UZ
Asterales	Asteraceae	*Sphaeranthus indicus* L.	Herb	Terrestrial	Native	Annual	LC	MZ, LZ
Fabales	Fabaceae	*Tephrosia purpurea* (L.) Pers.	Herb	Terrestrial	Native	Perennial	LC	UZ, MZ, LZ
Fabales	Fabaceae	*Trifolium campestre* Schreb.	Herb	Terrestrial	Exotic	Perennial	LC	UZ
Caryophyllales	Aizoaceae	*Trianthema portulacastrum* L.	Herb	Terrestrial	Native	Annual	NE	UZ
Zygophyllales	Zygophyllaceae	*Tribulus terrestris* L.	Herb	Terrestrial	Exotic	Annual	LC	MZ
Asterales	Asteraceae	*Tridax procumbens* L.	Herb	Terrestrial	Exotic	Annual	NE	UZ, LZ
Malvales	Malvaceae	*Urena lobata* L.	Herb	Terrestrial	Native	Perennial	LC	UZ
Lamiales	Scrophulariaceae	*Verbascum chinense* (L.) Santapau	Herb	Terrestrial	Native	Annual	NE	LZ
Lamiales	Verbenaceae	*Verbena supina* L.	Herb	Terrestrial	Exotic	Annual	NE	UZ
Fabales	Fabaceae	*Vicia monantha* Retz.	Herb	Terrestrial	Exotic	Perennial	NE	UZ
Lamiales	Scrophulariaceae	*Vicoa indica* (L.) DC.	Herb	Terrestrial	Native	Annual	NE	UZ, LZ
Asterales	Asteraceae	*Xanthium strumarium* L.	Herb	Terrestrial	Exotic	Annual	NE	UZ, MZ, LZ

NE: Not evaluated, LC: Least concern, UZ: Upper zone, MZ: Middle Zone, LZ: Lower Zone

Appendix. 5.5: Checklist of grass species recorded in the riparian zone of the Godavari River

Order	Family	Scientific Name	Habit	Habitat	Nativity	Nature	IUCN	Zone
Poales	Poaceae	*Apluda mutica* L.	Grass	Terrestrial	Native	Perennial	NE	UZ, MZ, LZ
Poales	Poaceae	*Bambusa bambos* (L.) Voss	Grass	Terrestrial	Native	Perennial	NE	UZ
Poales	Poaceae	*Cenchrus ciliaris* L.	Grass	Terrestrial	Native	Perennial	LC	UZ
Poales	Poaceae	*Chloris virgata* Sw.	Grass	Terrestrial	Native	Annual	NE	UZ, MZ, LZ
Poales	Poaceae	*Cynodon dactylon* (L.) Pers.	Grass	Terrestrial	Native	Perennial	NE	UZ, MZ, LZ
Poales	Poaceae	*Dactyloctenium aegyptium* (L.) Willd.	Grass	Terrestrial	Native	Perennial	LC	UZ, MZ, LZ
Poales	Poaceae	*Dichanthium annulatum* (Forssk.) Stapf	Grass	Terrestrial	Native	Perennial	NE	UZ, MZ, LZ
Poales	Poaceae	*Digitaria ciliaris* (Retz.) Koeler	Grass	Terrestrial	Exotic	Annual	NE	UZ
Poales	Poaceae	*Digitaria sanguinalis* (L.) Scop.	Grass	Terrestrial	Native	Annual	LC	LZ
Poales	Poaceae	*Dinebra retroflexa* (Vahl) Panz.	Grass	Terrestrial	Native	Annual	NE	UZ, MZ
Poales	Poaceae	*Echinochloa colona* (L.) Link	Grass	Terrestrial	Native	Annual	LC	UZ, MZ, LZ
Poales	Poaceae	*Eleusine indica* (L.) Gaertn.	Grass	Terrestrial	Native	Annual	LC	UZ, LZ
Poales	Poaceae	*Eragrostis tenella* (L.) P.Beauv. ex Roem. & Schult.	Grass	Terrestrial	Native	Annual	NE	MZ, LZ
Poales	Poaceae	*Heteropogon contortus* (L.) P. Beauv. ex Roem. & Schult.	Grass	Terrestrial	Native	Perennial	NE	UZ
Poales	Poaceae	*Imperata cylindrica* (L.) Raeusch.	Grass	Terrestrial	Native	Perennial	LC	MZ, LZ
Poales	Poaceae	*Ischaemum afrum* (J.F.Gmel.) Dandy	Grass	Terrestrial	Native	Perennial	NE	UZ
Poales	Poaceae	*Kyllinga brevifolia* Rottb.	Grass	Terrestrial	Native	Perennial	LC	UZ
Poales	Poaceae	*Oloptum miliaceum* (L.) Röser & Hamasha	Grass	Terrestrial	Native	Perennial	NE	UZ
Poales	Poaceae	*Saccharum bengalense* Retz.	Grass	Terrestrial	Native	Perennial	NE	LZ
Poales	Poaceae	*Saccharum spontaneum* L.	Grass	Terrestrial	Native	Perennial	LC	MZ, LZ
Poales	Poaceae	*Setaria verticillata* (L.) P.Beauv.	Grass	Terrestrial	Exotic	Annual	NE	UZ, MZ
Poales	Poaceae	*Sorghum halepense* (L.) Pers.	Grass	Terrestrial	Native	Perennial	NE	UZ, LZ
Poales	Poaceae	*Themeda triandra* Forssk.	Grass	Terrestrial	Native	Perennial	NE	UZ, MZ
Poales	Poaceae	*Thysanolaena latifolia* (Roxb. ex Hornem.) Honda	Grass	Terrestrial	Native	Perennial	NE	UZ
Poales	Typhaceae	*Typha angustifolia* L.	Grass	Aquatic	Native	Perennial	LC	MZ

NE: Not evaluated, LC: Least concern, UZ: Upper zone, MZ: Middle Zone, LZ: Lower Zone

Appendix 5.6. Checklist of Climber Species recorded in the riparian zone of the Godavari River

Order	Family	Scientific Name	Habit	Habitat	Nativity	Nature	IUCN	Zone
Fabales	Fabaceae	*Abrus precatorius* L.	Climber	Terrestrial	Native	Perennial	NE	MZ
Asparagales	Asparagaceae	*Asparagus racemosus* Willd.	Climber	Terrestrial	Native	Perennial	NE	LZ
Solanales	Convolvulaceae	*Calystegia hederacea* Wall.	Climber	Terrestrial	Exotic	Perennial	NE	UZ
Fabales	Fabaceae	*Canavalia rosea* (Sw.) DC.	Climber	Terrestrial	Exotic	Perennial	LC	UZ
Sapindales	Sapindaceae	*Cardiospermum halicacabum* L.	Climber	Terrestrial	Native	Perennial	LC	UZ, LZ
Vitales	Vitaceae	*Causonis trifolia* (L.) Raf.	Climber	Terrestrial	Native	Perennial	NE	UZ
Fabales	Fabaceae	*Clitoria ternatea* L.	Climber	Terrestrial	Native	Perennial	NE	UZ, MZ, LZ
Cucurbitales	Cucurbitaceae	*Coccinia grandis* (L.) Voigt	Climber	Terrestrial	Native	Perennial	LC	UZ
Ranunculales	Menispermaceae	*Cocculus carolinus* (L.) DC.	Climber	Terrestrial	Exotic	Perennial	NE	UZ
Myrtales	Combretaceae	*Combretum albidum* (Blanco) Merr.	Climber	Terrestrial	Native	Perennial	NE	UZ
Solanales	Convolvulaceae	*Convolvulus arvensis* L.	Climber	Terrestrial	Native	Perennial	NE	UZ
Gentianales	Apocynaceae	*Cryptostegia madagascariensis* Bojer ex Decne.	Climber	Terrestrial	Exotic	Perennial	NE	UZ
Dioscoreales	Dioscoreaceae	*Dioscorea communis* (L.) Caddick & Wilkin	Climber	Terrestrial	Exotic	Perennial	NE	UZ
Cucurbitales	Cucurbitaceae	*Diplocyclos palmatus* (L.) C.Jeffrey	Climber	Terrestrial	Native	Perennial	NE	UZ
Solanales	Convolvulaceae	*Distimake dissectus* (L.) P.Parm.	Climber	Terrestrial	Native	Perennial	NE	UZ
Solanales	Convolvulaceae	*Distimake quinquefolius* (Jacq.) Panero & S.Ulibarri	Climber	Terrestrial	Native	Perennial	NE	UZ
Gentianales	Apocynaceae	*Hemidesmus indicus* (L.) R.Br. ex Schult.	Climber	Terrestrial	Native	Perennial	NE	LZ
Solanales	Convolvulaceae	*Ipomoea cairica* (L.) Sweet	Climber	Terrestrial	Native	Perennial	LC	UZ
Solanales	Convolvulaceae	*Ipomoea hederifolia* L.	Climber	Terrestrial	Native	Annual	NE	UZ
Solanales	Convolvulaceae	*Ipomoea obscura* (L.) Ker Gawl.	Climber	Terrestrial	Native	Perennial	NE	UZ
Solanales	Convolvulaceae	*Ipomoea purpurea* (L.) Roth	Climber	Terrestrial	Native	Annual	NE	UZ
Fabales	Fabaceae	*Lathyrus pratensis* L.	Climber	Terrestrial	Exotic	Perennial	LC	UZ
Fabales	Fabaceae	*Mimosa quadrivalvis* L.	Climber	Terrestrial	Exotic	Perennial	NE	UZ
Fabales	Fabaceae	*Neonotonia wightii* (Wight & Arn.) Lackey	Climber	Terrestrial	Exotic	Perennial	NE	UZ
Malpighiales	Passifloraceae	*Passiflora foetida* L.	Climber	Terrestrial	Native	Perennial	NE	UZ, LZ
Fabales	Fabaceae	*Rhynchosia viscosa* DC.	Climber	Terrestrial	Native	Annual	NE	UZ
Asterales	Asteraceae	*Sphagneticola trilobata* (L.) Pruski	Climber	Terrestrial	Native	Perennial	NE	LZ
Cucurbitales	Cucurbitaceae	*Trichosanthes cucumeroides* L.	Climber	Terrestrial	Native	Perennial	NE	MZ

NE: Not evaluated, LC: Least concern, UZ: Upper zone, MZ: Middle Zone, LZ: Lower Zone

Appendix 5.7. Checklist of sedges recorded in the riparian zone of the Godavari River

Order	Family	Scientific Name	Habit	Habitat	Nativity	Nature	IUCN	Zone
Poales	Cyperaceae	*Cyperus alopecuroides* Rottb.	Sedges	Terrestrial	Native	Perennial	NE	UZ
Poales	Cyperaceae	*Cyperus rotundus* L.	Sedges	Terrestrial	Native	Perennial	LC	UZ, MZ, LZ
Poales	Cyperaceae	*Fimbristylis dichotomata* (L.) Vahl	Sedges	Terrestrial	Native	Perennial	NE	LZ
Poales	Cyperaceae	*Schoenoplectiella roylei* (Nees) Lye	Sedges	Aquatic	Native	Annual	LC	UZ

NE: Not evaluated, LC: Least concern, UZ: Upper zone, MZ: Middle Zone, LZ: Lower Zone

Appendix 6.11: Checklist of fishes recorded in the Godavari River

Order	Family	Scientific Name	Common name	IUCN Status	Zones
Cypriniformes	Cyprinidae	*Bangana dero*	Kalabans	LC	UZ
Cypriniformes	Cyprinidae	*Cyprinus carpio*	Wild common carp	VU	UZ
Cypriniformes	Cyprinidae	*Cirrhinus mrigala*	Mrigala	LC	UZ, MZ, LZ
Cypriniformes	Cyprinidae	*Cirrhinus reba*	Reba carp	LC	UZ, MZ, LZ
Cypriniformes	Cyprinidae	*Garra sp*	Sucker Fish	LC	LZ
Cypriniformes	Cyprinidae	*Garra mullya*	Sucker Fish	LC	UZ
Cypriniformes	Cyprinidae	*Hypophthalmichthys nobilis*	Bighead Carp	LC	MZ
Cypriniformes	Cyprinidae	*Labeo calbasu*	Orange-fin labeo	LC	MZ
Cypriniformes	Cyprinidae	*Labeo catla*	Catla	LC	UP, MZ, LZ
Cypriniformes	Cyprinidae	*Labeo rohita*	Rohu	LC	UZ
Cypriniformes	Cyprinidae	*Labeo bata*	Bata	LC	LZ
Cypriniformes	Cyprinidae	*Labeo boggut*	Boggut labeo	LC	LZ
Cypriniformes	Cyprinidae	*Labeo dussumieri*	Malabar labeo	LC	LZ
Cypriniformes	Cyprinidae	*Labeo fimbriatus*	Fringed-lipped peninsula carp	LC	LZ
Cypriniformes	Cyprinidae	*Labeo sp*			UZ, MZ, LZ
Cypriniformes	Cyprinidae	*Labeo sp1*			LZ
Cypriniformes	Cyprinidae	*Labeo sp2*			LZ
Cypriniformes	Cyprinidae	*Osteobrama vigorsii*	Godavari osteobrama	LC	UZ, MZ, LZ
Cypriniformes	Cyprinidae	*Osteobrama peninsularis*	Cotio	DD	UZ, MZ, LZ
Cypriniformes	Cyprinidae	*Pethia ticto*	Two-spot Barb	LC	UZ, LZ
Cypriniformes	Cyprinidae	*Puntius chola*	Swamp barb	LC	UZ, MZ, LZ
Cypriniformes	Cyprinidae	*Puntius conchonius*	Red Barb	LC	UZ
Cypriniformes	Cyprinidae	*Rohtee ogilbii*	Vatani rohtee	LC	LZ
Cypriniformes	Cyprinidae	*Systomus sarana*	Olive barb/Kuruva	LC	UZ, MZ, LZ
Cypriniformes	Cyprinidae	*Puntius sophore*	Spotfin swamp barb	LC	UZ
Cypriniformes	Cyprinidae	*Tariqilabeo latius*	Stone roller	LC	UZ
Cypriniformes	Cyprinidae	*Tor sp*	Mahseer		LZ
Cypriniformes	Danionidae	*Amblypharyngodon mola*	Mola carplet	LC	UZ
Cypriniformes	Danionidae	*Devario malabaricus*	Malabar danio	LC	UZ, LZ
Cypriniformes	Danionidae	*Devario devario*	Sind danio	LC	LZ
Cypriniformes	Danionidae	*Devario sp*	Devario	LC	UZ
Cypriniformes	Danionidae	*Laubuka laubuca*	Silver hatchet chela	LC	LZ
Cypriniformes	Danionidae	*Rasbora dandia*	Broad striped rasbora	LC	UZ
Cypriniformes	Danionidae	*Salmostoma bacaila*	Large Razorbelly Minnow	LC	UZ, MZ, LZ

Order	Family	Scientific Name	Common name	IUCN Status	Zones
Siluriformes	Bagridae	*Mystus cavasius*	Gangetic mystus	LC	UZ, MZ, LZ
Siluriformes	Bagridae	*Mystus vittatus*	Striped dwarf catfish		UZ, LZ
Siluriformes	Bagridae	*Mystus sp*	Mystus	LC	UZ
Siluriformes	Bagridae	*Rita kuturnee*	Deccan rita	LC	LZ
Siluriformes	Bagridae	*Rita rita*	Rita	LC	LZ
Siluriformes	Bagridae	*Sperata seenghala*	Long-whiskered catfish	LC	LZ
Siluriformes	Ailiidae	*Eutropiichthys vacha*	Bacha		LZ
Siluriformes	Pangasiidae	*Pangasius pangasius*	Pangas catfish	LC	UZ, MZ, LZ
Siluriformes	Siluridae	*Ompok bimaculatus*	Butter catfish	NT	UZ
Siluriformes	Siluridae	*Wallago attu*	Wallago/ baale	VU	UZ, MZ
Perciformes	Ambassidae	*Parambassis thomassi*	Westernghat Glassy perchlet	LC	UZ, MZ, LZ
Perciformes	Ambassidae	*Chanda nama*	Elongate glass-perchlet	LC	UZ, MZ, LZ
Clupeiformes	Clupeidae	*Tenualosa ilisha*	Hilsa shad	LC	LZ
Synbranchiformes	Mastacembelidae	*Mastacembelus armatus*	Zig-zag eel	LC	UZ
Synbranchiformes	Mastacembelidae	*Macrognathus pancalus*	Barred spiny eel	LC	UZ, LZ
Anabantiformes	Channidae	*Channa marulius*	Great Snakehead	LC	UZ, MZ, LZ
Anabantiformes	Channidae	*Channa punctatus*	Spotted Snakehead	LC	UZ, MZ, LZ
Anabantiformes	Channidae	*Channa striatus*	Striped Snakehead	LC	MZ, LZ
Cichliformes	Cichilidae	*Etroplus suratensis*	Pearlspot	LC	UZ, LZ
Cichliformes	Cichilidae	*Oreochromis mossambicus*	Mozambique tilapia	VU	UZ
Cichliformes	Cichilidae	*Oreochromis niloticus*	Nile tilapia	LC	UZ
Osteoglossiformes	Notopteridae	*Chitala chitala*	Indian featherback	NT	LZ
Osteoglossiformes	Notopteridae	*Notopterus synurus*	Bronze featherback	LC	UZ
Beloniformes	Belonidae	*Xenentodon cancila*	Freshwater garfish	LC	UZ
Gobiiformes	Gobiidae	*Glossogobius giuris*	Tank gobby	LC	UZ, LZ
Characiformes	Serrasalmidae	*Pygocentrus nattereri*	Roop Chand/Red belly prinaha	NE	UZ, MZ, LZ

LC: Least Concern, VU: Vulnerable, NT: Near Threatened, EN: Endangered, NR: Not recognized, UZ: Upper Zone, MZ: Middle Zone, LZ: Lower Zone.

Appendix 8.1. Checklist of birds recorded in the Godavari River

Order	Family	Common Name	Scientific Name	IUCN Status	WPA Schedule	Habitat	Distribution
Anseriformes	Anatidae	Lesser Whistling-Duck	*Dendrocygna javanica*	LC	Schedule-II	WB	UZ, MZ
Anseriformes	Anatidae	Bar-headed Goose	*Anser indicus*	LC	Schedule-II	WB	UZ, MZ, LZ
Anseriformes	Anatidae	Knob-billed Duck	*Sarkidiornis melanotos*	LC	Schedule-II	WB	MZ, LZ
Anseriformes	Anatidae	Ruddy Shelduck	*Tadorna ferruginea*	LC	Schedule-II	WB	UZ, MZ, LZ
Anseriformes	Anatidae	Common Shelduck	*Tadorna tadorna*	LC	Schedule-II	WB	UZ
Anseriformes	Anatidae	Cotton Pygmy-Goose	*Nettapus coromandelianus*	LC	Schedule-I	WB	UZ
Anseriformes	Anatidae	Northern Shoveler	*Spatula clypeata*	LC	Schedule-II	WB	UZ
Anseriformes	Anatidae	Eurasian Wigeon	*Mareca penelope*	LC	Schedule-II	WB	UZ
Anseriformes	Anatidae	Indian Spot-billed Duck	*Anas poecilorhyncha*	LC	Schedule-II	WB	UZ, MZ, LZ
Anseriformes	Anatidae	Northern Pintail	*Anas acuta*	LC	Schedule-II	WB	UZ, MZ, LZ
Anseriformes	Anatidae	Common Teal	*Anas crecca*	LC	Schedule-II	WB	UZ
Anseriformes	Anatidae	Red-crested Pochard	*Netta rufina*	LC	Schedule-II	WB	UZ
Anseriformes	Anatidae	Common Pochard	*Aythya ferina*	VU	Schedule-I	WB	UZ
Anseriformes	Anatidae	Common Merganser	*Mergus merganser*	LC	Schedule-II	WB	LZ
Galliformes	Phasianidae	Indian Peafowl	*Pavo cristatus*	LC	Schedule-I	T	UZ, MZ
Galliformes	Phasianidae	Grey Francolin	*Ortygornis pondicerianus*	LC	Schedule-II	T	UZ, LZ
Galliformes	Phasianidae	Rain Quail	*Coturnix coromandelica*	LC	Schedule-II	T	MZ
Galliformes	Phasianidae	Jungle Bush-Quail	*Perdicula asiatica*	LC	Schedule-II	T	UZ
Phoenicopteriformes	Phoenicopteridae	Greater Flamingo	*Phoenicopterus roseus*	LC	Schedule-II	WB	UZ
Podicipediformes	Podicipedidae	Little Grebe	*Tachybaptus ruficollis*	LC	Schedule-II	WB	UZ
Columbiformes	Columbidae	Rock Pigeon	*Columba livia*	LC	-	T	UZ, MZ
Columbiformes	Columbidae	Eurasian Collared-Dove	*Streptopelia decaocto*	LC	Schedule-II	T	UZ, MZ, LZ
Columbiformes	Columbidae	Red Collared-Dove	*Streptopelia tranquebarica*	LC	Schedule-II	T	UZ
Columbiformes	Columbidae	Spotted Dove	*Spilopelia chinensis*	LC	Schedule-II	T	UZ, MZ, LZ
Columbiformes	Columbidae	Laughing Dove	*Spilopelia senegalensis*	LC	Schedule-II	T	UZ, MZ, LZ
Columbiformes	Columbidae	Yellow-footed Green-Pigeon	*Treron phoenicopterus*	LC	Schedule-II	T	UZ, LZ
Pterocliformes	Pteroclidae	Chestnut-bellied Sandgrouse	*Pterocles exustus*	LC	Schedule-II	T	UZ
Cuculiformes	Cuculidae	Greater Coucal	*Centropus sinensis*	LC	Schedule-II	T	UZ, MZ, LZ
Cuculiformes	Cuculidae	Blue-faced Malkoha	*Phaenicophaeus viridirostris*	LC	Schedule-II	T	UZ, MZ, LZ
Cuculiformes	Cuculidae	Asian Koel	*Eudynamys scolopaceus*	LC	Schedule-II	T	UZ, MZ, LZ
Cuculiformes	Cuculidae	Common Hawk-Cuckoo	*Hierococcyx varius*	LC	Schedule-II	T	UZ, LZ
Cuculiformes	Cuculidae	Indian Cuckoo	*Cuculus micropterus*	LC	Schedule-II	T	MZ
Caprimulgiformes	Apodidae	Asian Palm Swift	*Cypsiurus balasiensis*	LC	Schedule-II	T	MZ, LZ

Order	Family	Common Name	Scientific Name	IUCN Status	WPA Schedule	Habitat	Distribution
Gruiformes	Rallidae	Eurasian Coot	*Fulica atra*	LC	Schedule-II	WB	UZ
Gruiformes	Rallidae	Grey-headed Swamphen	*Porphyrio poliocephalus*	NR	Schedule-II	WB	UZ
Gruiformes	Rallidae	White-breasted Waterhen	*Amaurornis phoenicurus*	LC	Schedule-II	WB	UZ, MZ
Gruiformes	Gruidae	Demoiselle Crane	*Grus virgo*	LC	Schedule-I	WB	UZ
Charadriiformes	Recurvirostridae	Black-winged Stilt	*Himantopus himantopus*	LC	Schedule-II	WB	UZ, MZ, LZ
Charadriiformes	Charadriidae	Little Ringed Plover	*Charadrius dubius*	LC	Schedule-II	WB	UZ, MZ
Charadriiformes	Charadriidae	River Lapwing	*Vanellus duvaucelii*	NT	Schedule-II	WB	LZ
Charadriiformes	Charadriidae	Red-wattled Lapwing	*Vanellus indicus*	LC	Schedule-II	WB	UZ, MZ, LZ
Charadriiformes	Jacanidae	Pheasant-tailed Jacana	*Hydrophasianus chirurgus*	LC	Schedule-II	WB	UZ
Charadriiformes	Scolopacidae	Black-tailed Godwit	*Limosa limosa*	NT	Schedule-II	WB	UZ
Charadriiformes	Scolopacidae	Common Sandpiper	*Actitis hypoleucos*	LC	Schedule-II	WB	UZ
Charadriiformes	Scolopacidae	Common Redshank	*Tringa totanus*	LC	Schedule-II	WB	UZ, LZ
Charadriiformes	Scolopacidae	Common Greenshank	*Tringa nebularia*	LC	Schedule-I	WB	UZ
Charadriiformes	Scolopacidae	Temminck's Stint	*Calidris temminckii*	LC	Schedule-II	WB	UZ, MZ, LZ
Charadriiformes	Glareolidae	Small Pratincole	*Glareola lactea*	LC	Schedule-II	WB	UZ, LZ
Charadriiformes	Laridae	Brown-headed Gull	*Chroicocephalus brunnicephalus*	LC	Schedule-II	WB	UZ
Charadriiformes	Laridae	Pallas's Gull	*Ichthyaetus ichthyaetus*	LC	Schedule-II	WB	UZ, LZ
Charadriiformes	Laridae	Indian Skimmer	*Rynchops albicollis*	EN	Schedule-I	WB	MZ
Charadriiformes	Laridae	Whiskered Tern	*Chlidonias hybrida*	LC	Schedule-II	WB	UZ, LZ
Charadriiformes	Laridae	River Tern	*Sterna aurantia*	VU	Schedule-I	WB	UZ, MZ, LZ
Charadriiformes	Laridae	Black-bellied Tern	*Sterna acuticauda*	EN	Schedule-I	WB	UZ, MZ, LZ
Ciconiiformes	Ciconiidae	Asian Openbill	*Anastomus oscitans*	LC	Schedule-II	WB	UZ, MZ, LZ
Ciconiiformes	Ciconiidae	Woolly-necked Stork	*Ciconia episcopus*	NT	Schedule-II	WB	UZ, MZ
Ciconiiformes	Ciconiidae	Painted Stork	*Mycteria leucocephala*	LC	Schedule-II	WB	UZ, MZ
Suliformes	Anhingidae	Oriental Darter	*Anhinga melanogaster*	NT	Schedule-II	WB	MZ
Suliformes	Phalacrocoracidae	Little Cormorant	*Microcarbo niger*	LC	Schedule-II	WB	UZ, MZ, LZ
Suliformes	Phalacrocoracidae	Great Cormorant	*Phalacrocorax carbo*	LC	Schedule-II	WB	UZ, MZ, LZ
Suliformes	Phalacrocoracidae	Indian Cormorant	*Phalacrocorax fuscicollis*	LC	Schedule-II	WB	UZ, MZ, LZ
Pelecaniformes	Ardeidae	Black-crowned Night Heron	*Nycticorax nycticorax*	LC	Schedule-II	WB	MZ
Pelecaniformes	Ardeidae	Little Egret	*Egretta garzetta*	LC	Schedule-II	WB	UZ, MZ, LZ
Pelecaniformes	Ardeidae	Western Reef-Egret	*Egretta gularis*	LC	Schedule-II	WB	MZ, LZ
Pelecaniformes	Ardeidae	Striated Heron	*Butorides striata*	LC	Schedule-II	WB	LZ

Order	Family	Common Name	Scientific Name	IUCN Status	WPA Schedule	Habitat	Distribution
Pelecaniformes	Ardeidae	Indian Pond-Heron	*Ardeola grayii*	LC	Schedule-II	WB	UZ, MZ, LZ
Pelecaniformes	Ardeidae	Eastern Cattle Egret	*Bubulcus coromandus*	NR	Schedule-II	WB	UZ, MZ, LZ
Pelecaniformes	Ardeidae	Great Egret	*Ardea alba*	LC	Schedule-II	WB	UZ, MZ
Pelecaniformes	Ardeidae	Intermediate Egret	*Ardea intermedia*	LC	Schedule-II	WB	UZ, MZ, LZ
Pelecaniformes	Ardeidae	Grey Heron	*Ardea cinerea*	LC	Schedule-II	WB	UZ, MZ, LZ
Pelecaniformes	Ardeidae	Purple Heron	*Ardea purpurea*	LC	Schedule-II	WB	UZ, MZ
Pelecaniformes	Threskiornithidae	Glossy Ibis	*Plegadis falcinellus*	LC	Schedule-II	WB	UZ, LZ, MZ
Pelecaniformes	Threskiornithidae	Black-headed Ibis	*Threskiornis melanocephalus*	NT	Schedule-II	WB	UZ, MZ
Pelecaniformes	Threskiornithidae	Red-naped Ibis	*Pseudibis papillosa*	LC	Schedule-II	WB	UZ, MZ, LZ
Pelecaniformes	Threskiornithidae	Eurasian Spoonbill	*Platalea leucorodia*	LC	Schedule-I	WB	UZ
Accipitriformes	Pandionidae	Osprey	*Pandion haliaetus*	LC	Schedule-I	WAB	LZ
Accipitriformes	Accipitridae	Black-winged Kite	*Elanus caeruleus*	LC	Schedule-II	T	UZ, MZ
Accipitriformes	Accipitridae	Oriental Honey-buzzard	*Pernis ptilorhynchus*	LC	Schedule-II	T	UZ, LZ
Accipitriformes	Accipitridae	Crested Serpent-Eagle	*Spilornis cheela*	LC	Schedule-I	T	UZ
Accipitriformes	Accipitridae	Short-toed Snake-Eagle	*Circaetus gallicus*	LC	Schedule-I	T	UZ, MZ
Accipitriformes	Accipitridae	White-eyed Buzzard	*Butastur teesa*	LC	Schedule-I	T	MZ
Accipitriformes	Accipitridae	Western Marsh Harrier	*Circus aeruginosus*	LC	Schedule-I	WAB	UZ
Accipitriformes	Accipitridae	Shikra	*Accipiter badius*	LC	Schedule-I	T	UZ, MZ, LZ
Accipitriformes	Accipitridae	Black Kite	*Milvus migrans*	LC	Schedule-II	T	UZ, MZ
Accipitriformes	Accipitridae	Grey-headed Fish-Eagle	*Icthyophaga ichthyaetus*	NT	Schedule-I	WAB	MZ, LZ
Strigiformes	Strigidae	Eurasian Eagle-Owl	*Bubo bubo*	LC	Schedule-I	T	MZ
Strigiformes	Strigidae	Spotted Owlet	*Athene brama*	LC	Schedule-II	T	UZ, MZ
Bucerotiformes	Upupidae	Eurasian Hoopoe	*Upupa epops*	LC	Schedule-II	T	UZ, MZ, LZ
Bucerotiformes	Bucerotidae	Indian Grey Hornbill	*Ocyceros birostris*	LC	Schedule-II	T	MZ, LZ
Coraciiformes	Alcedinidae	Common Kingfisher	*Alcedo atthis*	LC	Schedule-II	WAB	UZ, MZ, LZ
Coraciiformes	Alcedinidae	Stork-billed Kingfisher	*Pelargopsis capensis*	LC	Schedule-II	WAB	MZ
Coraciiformes	Alcedinidae	White-throated Kingfisher	*Halcyon smyrnensis*	LC	Schedule-II	WAB	UZ, MZ, LZ
Coraciiformes	Alcedinidae	Pied Kingfisher	*Ceryle rudis*	LC	Schedule-II	WAB	UZ, MZ, LZ
Coraciiformes	Meropidae	Green Bee-eater	*Merops orientalis*	LC	Schedule-II	T	UZ, LZ, MZ
Coraciiformes	Meropidae	Blue-tailed Bee-eater	*Merops philippinus*	LC	Schedule-II	WAB	MZ, LZ
Coraciiformes	Coraciidae	Indian Roller	*Coracias benghalensis*	LC	Schedule-II	T	UZ, MZ
Piciformes	Megalaimidae	Coppersmith Barbet	*Psilopogon haemacephalus*	LC	Schedule-II	T	UZ, MZ, LZ
Piciformes	Megalaimidae	Brown-headed Barbet	*Psilopogon zeylanicus*	LC	Schedule-II	T	UZ
Piciformes	Picidae	Fulvous-breasted Woodpecker	*Dendrocopos macei*	LC	Schedule-II	T	UZ

Order	Family	Common Name	Scientific Name	IUCN Status	WPA Schedule	Habitat	Distribution
Piciformes	Picidae	Greater Flameback	*Chrysocolaptes guttacristatus*	LC	Schedule-II	T	LZ
Falconiformes	Falconidae	Common Kestrel	*Falco tinnunculus*	LC	Schedule-II	T	LZ
Psittaciformes	Psittaculidae	Alexandrine Parakeet	*Psittacula eupatria*	NT	Schedule-II	T	MZ, LZ
Psittaciformes	Psittaculidae	Rose-ringed Parakeet	*Psittacula krameri*	LC	Schedule-II	T	UZ, MZ, LZ
Psittaciformes	Psittaculidae	Plum-headed Parakeet	*Psittacula cyanocephala*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Campephagidae	Black-headed Cuckooshrike	*Lalage melanoptera*	LC	Schedule-II	T	UZ, MZ
Passeriformes	Oriolidae	Indian Golden Oriole	*Oriolus kundoo*	LC	Schedule-II	T	UZ, LZ
Passeriformes	Vangidae	Common Woodshrike	*Tephrodornis pondicerianus*	LC	Schedule-II	T	UZ
Passeriformes	Aegithinidae	Common Iora	*Aegithina tiphia*	LC	Schedule-II	T	UZ, LZ
Passeriformes	Aegithinidae	Marshall's Iora	*Aegithina nigrolutea*	LC	Schedule-II	T	LZ
Passeriformes	Rhipiduridae	White-browed Fantail	*Rhipidura aureola*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Dicruridae	Black Drongo	*Dicrurus macrocercus*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Laniidae	Brown Shrike	*Lanius cristatus*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Laniidae	Bay-backed Shrike	*Lanius vittatus*	LC	Schedule-II	T	UZ, MZ
Passeriformes	Laniidae	Long-tailed Shrike	*Lanius schach*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Laniidae	Great Grey Shrike	*Lanius excubitor*	LC	Schedule-II	T	UZ
Passeriformes	Corvidae	Rufous Treepie	*Dendrocitta vagabunda*	LC	Schedule-II	T	LZ
Passeriformes	Corvidae	House Crow	*Corvus splendens*	LC	-	T	UZ, MZ, LZ
Passeriformes	Corvidae	Large-billed Crow	*Corvus macrorhynchos*	LC	Schedule-II	T	UZ, LZ
Passeriformes	Alaudidae	Rufous-tailed Lark	*Ammomanes phoenicura*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Alaudidae	Ashy-crowned Sparrow-Lark	*Eremopterix griseus*	LC	Schedule-II	T	UZ, LZ
Passeriformes	Alaudidae	Singing Bushlark	*Mirafra javanica*	LC	Schedule-II	T	MZ
Passeriformes	Cisticolidae	Common Tailorbird	*Orthotomus sutorius*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Cisticolidae	Jungle Prinia	*Prinia sylvatica*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Cisticolidae	Ashy Prinia	*Prinia socialis*	LC	Schedule-II	T	UZ, LZ, MZ
Passeriformes	Cisticolidae	Plain Prinia	*Prinia inornata*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Cisticolidae	Zitting Cisticola	*Cisticola juncidis*	LC	Schedule-II	T	MZ, LZ
Passeriformes	Acrocephalidae	Blyth's Reed Warbler	*Acrocephalus dumetorum*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Acrocephalidae	Clamorous Reed Warbler	*Acrocephalus stentoreus*	LC	Schedule-II	T	LZ
Passeriformes	Hirundinidae	Dusky Crag-Martin	*Ptyonoprogne concolor*	LC	Schedule-II	T	UZ, MZ
Passeriformes	Hirundinidae	Barn Swallow	*Hirundo rustica*	LC	Schedule-II	WAB	UZ, MZ, LZ
Passeriformes	Hirundinidae	Wire-tailed Swallow	*Hirundo smithii*	LC	Schedule-II	WAB	UZ, MZ, LZ
Passeriformes	Hirundinidae	Red-rumped Swallow	*Cecropis daurica*	LC	Schedule-II	WAB	UZ

Order	Family	Common Name	Scientific Name	IUCN Status	WPA Schedule	Habitat	Distribution
Passeriformes	Hirundinidae	Streak-throated Swallow	*Petrochelidon fluvicola*	LC	Schedule-II	WAB	UZ, MZ, LZ
Passeriformes	Pycnonotidae	White-browed Bulbul	*Pycnonotus luteolus*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Pycnonotidae	Red-whiskered Bulbul	*Pycnonotus jocosus*	LC	Schedule-II	T	LZ
Passeriformes	Pycnonotidae	Red-vented Bulbul	*Pycnonotus cafer*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Pycnonotidae	White-eared Bulbul	*Pycnonotus leucotis*	LC	Schedule-II	T	UZ
Passeriformes	Phylloscopidae	Common Chiffchaff	*Phylloscopus collybita*	LC	Schedule-II	T	UZ
Passeriformes	Phylloscopidae	Greenish Warbler	*Phylloscopus trochiloides*	LC	Schedule-II	T	UZ, MZ
Passeriformes	Sylviidae	Lesser Whitethroat	*Curruca curruca*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Paradoxornithidae	Yellow-eyed Babbler	*Chrysomma sinense*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Zosteropidae	Indian White-eye	*Zosterops palpebrosus*	LC	Schedule-II	T	UZ, LZ
Passeriformes	Timaliidae	Tawny-bellied Babbler	*Dumetia hyperythra*	LC	Schedule-II	T	UZ
Passeriformes	Leiothrichidae	Large Grey Babbler	*Argya malcolmi*	LC	Schedule-II	T	UZ
Passeriformes	Leiothrichidae	Jungle Babbler	*Argya striata*	LC	Schedule-II	T	UZ
Passeriformes	Leiothrichidae	Yellow-billed Babbler	*Argya affinis*	LC	Schedule-II	T	MZ, LZ
Passeriformes	Leiothrichidae	Common Babbler	*Argya caudata*	LC	Schedule-II	T	MZ
Passeriformes	Sturnidae	Rosy Starling	*Pastor roseus*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Sturnidae	Asian Pied Starling	*Gracupica contra*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Sturnidae	Brahminy Starling	*Sturnia pagodarum*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Sturnidae	Common Myna	*Acridotheres tristis*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Muscicapidae	Indian Robin	*Copsychus fulicatus*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Muscicapidae	Oriental Magpie-Robin	*Copsychus saularis*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Muscicapidae	Tickell's Blue Flycatcher	*Cyornis tickelliae*	LC	Schedule-II	T	MZ
Passeriformes	Muscicapidae	Bluethroat	*Luscinia svecica*	LC	Schedule-II	T	MZ, LZ
Passeriformes	Muscicapidae	White-capped Redstart	*Phoenicurus leucocephalus*	LC	Schedule-II	WAB	UZ
Passeriformes	Muscicapidae	Black Redstart	*Phoenicurus ochruros*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Muscicapidae	Blue Rock-Thrush	*Monticola solitarius*	LC	Schedule-II	T	LZ
Passeriformes	Muscicapidae	Siberian Stonechat	*Saxicola maurus*	NR	Schedule-II	T	UZ
Passeriformes	Muscicapidae	Pied Bushchat	*Saxicola caprata*	LC	Schedule-II	T	UZ, LZ, MZ
Passeriformes	Muscicapidae	Wheatear sp	*Oenanthe sp.*	-	-	T	MZ
Passeriformes	Dicaeidae	Pale-billed Flowerpecker	*Dicaeum erythrorhynchos*	LC	Schedule-II	T	LZ
Passeriformes	Nectariniidae	Purple-rumped Sunbird	*Leptocoma zeylonica*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Nectariniidae	Purple Sunbird	*Cinnyris asiaticus*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Chloropseidae	Golden-fronted Leafbird	*Chloropsis aurifrons*	LC	Schedule-II	T	LZ
Passeriformes	Ploceidae	Baya Weaver	*Ploceus philippinus*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Estrildidae	Indian Silverbill	*Euodice malabarica*	LC	Schedule-II	T	UZ, MZ, LZ

Order	Family	Common Name	Scientific Name	IUCN Status	WPA Schedule	Habitat	Distribution
Passeriformes	Estrildidae	Scaly-breasted Munia	*Lonchura punctulata*	LC	Schedule-II	T	MZ, LZ
Passeriformes	Estrildidae	Tricoloured Munia	*Lonchura malacca*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Estrildidae	Red Munia	*Amandava amandava*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Passeridae	House Sparrow	*Passer domesticus*	LC	Schedule-II	T	UZ, MZ
Passeriformes	Passeridae	Yellow-throated Sparrow	*Gymnoris xanthocollis*	LC	Schedule-II	T	LZ
Passeriformes	Motacillidae	Grey Wagtail	*Motacilla cinerea*	LC	Schedule-II	WAB	UZ
Passeriformes	Motacillidae	Western Yellow Wagtail	*Motacilla flava*	LC	Schedule-II	WAB	UZ, MZ
Passeriformes	Motacillidae	Citrine Wagtail	*Motacilla citreola*	LC	Schedule-II	WAB	UZ, LZ
Passeriformes	Motacillidae	White-browed Wagtail	*Motacilla maderaspatensis*	LC	Schedule-II	WAB	UZ, MZ, LZ
Passeriformes	Motacillidae	White Wagtail	*Motacilla alba*	LC	Schedule-II	WAB	UZ, MZ, LZ
Passeriformes	Motacillidae	Paddyfield Pipit	*Anthus rufulus*	LC	Schedule-II	T	UZ, MZ, LZ
Passeriformes	Emberizidae	Crested Bunting	*Emberiza lathami*	LC	Schedule-II	T	UZ
Passeriformes	Emberizidae	Black-headed Bunting	*Emberiza melanocephala*	LC	Schedule-II	T	LZ

LC: Least concern UZ: Upper zone, MZ: Middle zone, LZ: Lower zone

Appendix 9.1: Checklist of Mammals recorded in the Godavari River

Order	Family	Scientific Name	Common Name	IUCN Status	IWPA Schedule	Zone
Artiodactyla	Bovidae	*Antilope cervicapra*	Blackbuck	LC	Schedule I	MZ
Carnivora	Canidae	*Canis aureus*	Golden Jackal	LC	Schedule I	UZ, MZ, LZ
Carnivora	Felidae	*Felis chaus*	Jungle Cat	LC	Schedule I	UZ
Rodentia	Sciuridae	*Funambulus palmarum*	Common Palm Squirrel	LC	Schedule IV	UZ, LZ
Rodentia	Sciuridae	*Funambulus pennantii*	Five-striped Palm Squirrel	LC	Schedule IV	UZ, MZ
Carnivora	Herpestidae	*Herpestes edwardsii*	Indian Grey Mongoose	LC	Schedule I	UZ, MZ, LZ
Carnivora	Herpestidae	*Herpestes smithii*	Ruddy Mongoose	LC	Schedule I	UZ, MZ
Rodentia	Hystricidae	*Hystrix indica*	Indian Crested Porcupine	LC	Schedule I	UZ
Lagomorpha	Leporidae	*Lepus nigricollis*	Indian Hare	LC	Schedule II	UZ, MZ, LZ
Primates	Cercopithecidae	*Macaca mulatta*	Rhesus Macaque	LC	Schedule IV	UZ, MZ, LZ
Carnivora	Viverridae	*Paradoxurus hermaphroditus*	Asian Palm Civet	LC	Schedule I	UZ, MZ, LZ
Chiroptera	Pteropodidae	*Pteropus medius*	Indian Flying Fox	LC	Schedule II	UZ, MZ
Primates	Cercopithecidae	*Semnopithecus entellus*	Northern Plains Gray Langur	LC	Schedule II	UZ, MZ, LZ
Artiodactyla	Suidae	*Sus scrofa*	Wild boar	LC	Schedule II	UZ, MZ, LZ

LC: Least concern UZ: Upper zone, MZ: Middle zone, LZ: Lower zone

Notes

National River Conservation Directorate (NRCD)
Ministry of Jal Shakti
Department of Water Resources, River Development & Ganga Rejuvenation
1st Floor Pandit Deendayal Antyodaya Bhawan
CGO Complex Lodhi Road,
New Delhi-110 003
http://nrcd.nic.in,
Ph no.: 01124369380, 01124364625

सत्यमेव जयते

हमारा संकल्प नदियों का कायाकल्प
We Pledge To Conserve Our Rivers

GACMC/NCRR
Ganga Aqualife Conservation Monitoring Centre/National Centre for River Research
nrcd@wii.gov.in,
Tel.: 0135 264210, 2646480

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Wildlife Institute of India
Chandrabani, Dehradun, Uttarakhand
https://wii.gov.in

XPRESSIONS: 9219552563 | DOC NO. XPS