Indian Journal of Geo Marine Sciences
Vol. 52 (01), January 2023, pp. 15-23
DOI: 10.56042/ijms.v52i01.5436

# Spatio-temporal changes in the Godavari mangroves: A study examining land-use change and sustainable management

K Jayakumar

Centre for Remote Sensing and Geoinformatics, Sathyabama Institute of Science and Technology, Rajiv Gandhi Road, Jeppiaar Nagar, Sholinganallur, Chennai – 600 119, India

[E-mail: jaikumar.gis@gmail.com]

*Received 11 May 2021; revised 21 December 2022*

Geospatial approaches were used to explore the socio-economic and environmental aspects of land use changes in the mangroves of Godavari, Andhra Pradesh, India. Large-scale changes were discovered through satellite images in mangroves. Socio-economic information was also gathered using GPS and environmental changes were examined and correlated. Additional parameters were recorded, including precipitation, temperature, freshwater flow, geomorphology, and topography to relate to modifications in the Godavari mangroves. The area of mangrove forest rose from 15,024 ha to 19,694 ha over 35 years (1977 to 2012), indicating the success of government and private afforestation measures. A socio-economic survey in villages showed that 57 % of the population felt that the main reasons for the enhanced mangrove region were restoration activities and natural phenomena, while 37 % thought that the mangrove area had decreased owing to aquaculture, agriculture, illegal harvesting, local consumption, and enhanced industrial activity, while the remaining 6 % thought that the mangrove area is decreased.

[**Keywords**: Afforestation, Aquaculture, Mangroves, Remote sensing, Restoration, Socioeconomics, Wetland]

## Introduction

Mangroves are salt-tolerant plants that grow in intertidal regions along tropical and subtropical coasts, primarily between 30º N and 30º S latitudes[1]. This most productive ecosystem occupies a worldwide region of roughly 15.2 million hectares[2]. Mangroves offer numerous goods and services, including coastline protection from nature disasters[3-9]. Their global distribution is influenced by numerous environmental factors, such as climate, salinity, freshwater supply, topography, geomorphology, temperature, sediment input, tidal flow, bathymetry, and wave energy[10]. At the local level, the extent of mangrove cover is controlled by other environmental variables such as the fresh water flow from the upper catchments and the quantity and quality of sediments transported with the fresh water flow, tidal range, etc.[10-14].

Anthropogenic pressures, apart from environmental variables, play a significant role in maintaining mangrove health[15]. Human activities such as aquaculture, urbanization, agriculture, and tourism, destroy mangroves globally. The effect of aquaculture on mangrove forests is mainly significant, particularly in Asia, which supplies 90 % of world aquaculture production and where approximately 10,000 km² of coastal area has been transformed into shrimp ponds[16-17]. Urbanization has similarly led to loss of coastal mangroves in many parts of the world, such as in Recife, Freetown, Douala, Maracaibo, Lagos, Mumbai, Kolkata, Rangoon, Bangkok, Jakarta, and Singapore[17]. All of these human activities are synergistically governing the development, existence and species diversity of mangroves. The combined impact of these parameters must be quantified to prepare and implement efficient plans for mangrove preservation, restoration and management. A geospatial scheme, for example, can promote and accelerate management operations. Mapping mangroves by field inventory is extremely difficult, time-consuming, and expensive. Therefore, a more accurate and cost-effective remote sensing tool was chosen to map, monitor and record modifications and their effects on the mangrove environment[18-22]. To develop information on various aspects of the coastal and marine environment, regular, synoptic and multi-spectral data from various satellite platforms are available[23-25]. At local scales, several studies have used satellite data to characterize and map mangrove forests[12,26-28]. Remote sensing therefore allows for quantitative and qualitative assessment across large and inaccessible areas. This paper describes and analyzes the modifications in the Godavari mangroves and related land use from 1977 to 2012 and also analyzes the environmental factors that may have influenced changes in the mangrove environment.

## Materials and Methods

### Study area

The research is being conducted in the East Godavari district mangroves of Godavari, Andhra Pradesh, India (Fig. 1), which is situated between latitudes 16° 30' and 17° 00' North and 82° 10' and 82° 25' East with a height of 5 m. The Godavari River is India's second longest river with a total catchment area of 3,14,685 km$^2$ and a total length of 1,440 km of which about two-thirds of the river flow discharges into the Bay of Bengal. The total area of the Godavari mangroves is about 33,263 ha, according to the Andhra Pradesh Forest Department. In July 1978, Andhra Pradesh's government proclaimed a

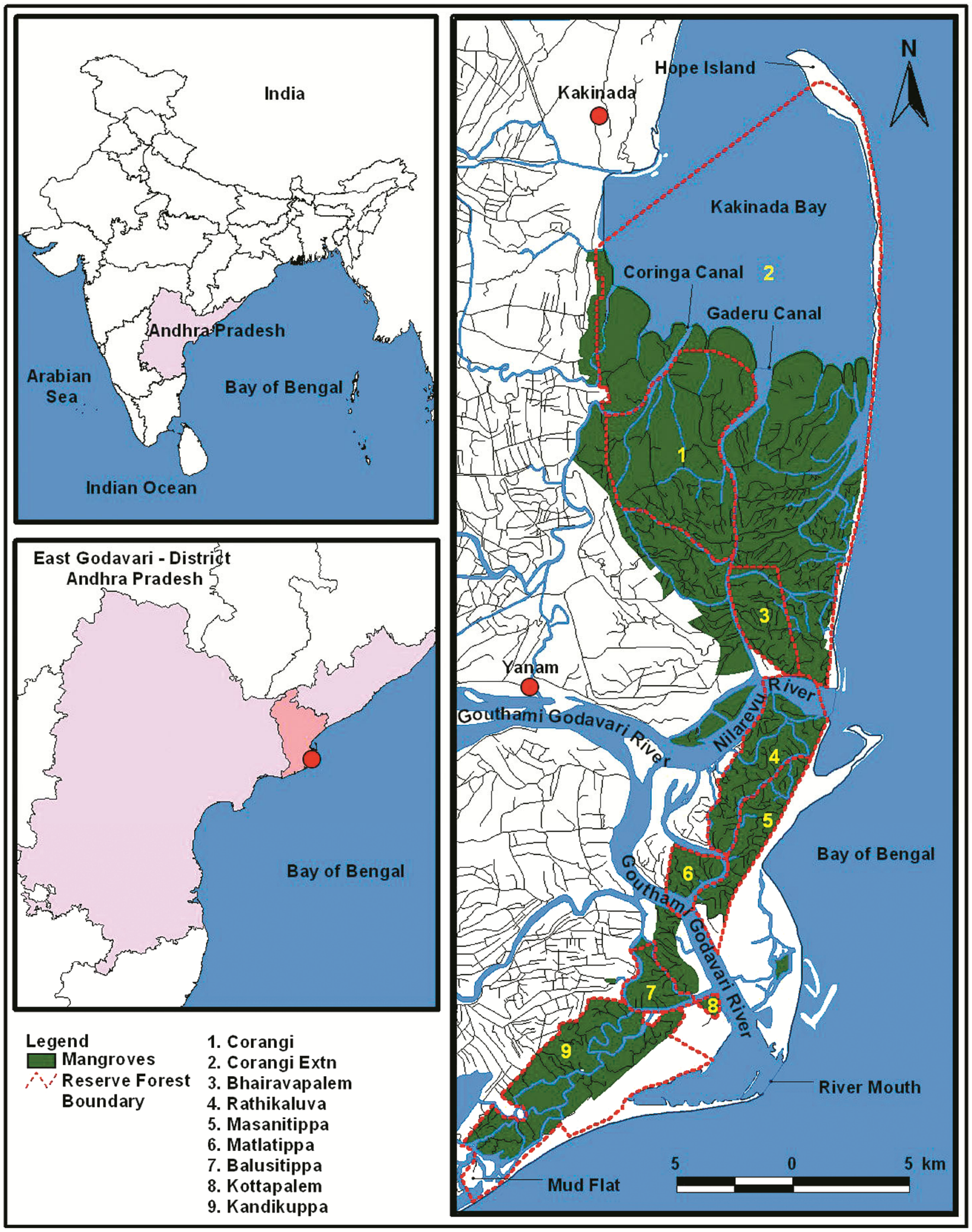


Fig. 1 — Study area map of Godavari mangrove wetland

portion of Godavari's mangrove system as the Coringa Wildlife Sanctuary, covering an area of approximately 23,570 ha. The mangroves of Godavari consist of nine Reserve Forests (RFs), the first three are Coringa, Coringa Extension and Bhairavapalem RF regions, which consist of the Coringa Wildlife Sanctuary (CWS) and are situated in the northern portion of the Godavari delta. The other six RFs (Rathikalava, Masanitippa, Matlatippa, Balusutippa, Kothapalem and Kandikuppa) are located in the southern part of the wetland. The research region consists of three administrative mandals, namely Tallarevu, Island Polavaram and Katrenikona that are often susceptible to floods and cyclones. The region has an average annual rainfall and temperature of 1,110 mm and 28 °C, respectively.

#### Data collection and analysis

Temporal satellite images with different spectral resolutions were used for this study. The satellite images include Landsat-4 MSS from1977 and IRS 1B LISS 2 from 1988, IRS 1C LISS 3 from 2001, IRS P6 LISS 3 from 2008 and Resourcesat-2 LISS 4 from 2012 (https://landsat.usgs.gov) and NRSC (https:// www.nrsc.gov.in/). Cloud-free images were used to rectify geometric distortions[29]. Visual image interpretation was used to analyse changes in mangrove coverage by using the temporal satellite images. In order to generate the Godavari mangrove wetland maps for the years 1977, 1988, 2001, 2008 and 2012, on screen digitization technique was adopted using ERDAS Imagine software. LISS 4 image from 2012 and Survey of India toposheets from 1975 were used to generate Godavari mangrove geomorphology, drainage networks and topography. Rainfall and temperature data collected from Kakinada meteorological stations located in Kakinada about 12 km north of the Godavari mangroves were purchased from the Indian Metrological Department (IMD). Freshwater monthly discharge data for the mangrove forest for 1977 to 2011 period were collected from the Dowlaiswaram barrage, Chief Executive Engineering Department, Government of Andhra Pradesh which is located about 60 km from the study area. The discharge from the barrage feeds freshwater into Coringa Wildlife Sanctuary by two significant canals, the Gaderu and the Coringa as well as the Nilarevu and Gautami Godavari River and their tributaries for regions beyond the sanctuary. All data sets were statistically analyzed using MS Excel software for the annual, monthly and seasonal time series and related landuse and socioeconomic change. In June 2012, in a visit to 39 villages in and around the Godavari mangroves and collected socioeconomic data on local uses of the mangroves, and awareness and perceptions about the status and recent development of the mangrove forest cover. Fishermen from several villages who were long-term (30-70 yr) residents were interviewed at random to identify and record the utilization of mangroves by the local people. Only one person per household was interviewed to avoid repetition of information. The interview was conducted in Telugu (regional language) and later translated into English. Ground-truth information was collected in the Godavari wetland for the verification of the mangrove maps prepared using satellite images. A Global Positioning System (GPS) receiver was used in the entire field data collection to identify the locations in geographic reference.

## Results

#### Remote sensing data

Wetland maps for Godavari on a 1:50,000 scale showed that mangrove forest cover increased over a period of 35 years (1977 to 2012) from 15,024 to 19,694 (Table 1, Fig. 2). The average annual rate of increase in forest cover was about 331 ha. Besides changes in the cover of mangrove forests, the dynamics of salt pans which have existed in 1938 and the growth of aquaculture since 1988 represent a further significant shift in land use which occurred in the study region (Table 1) with the area of aquaculture ponds expanding from 1,235 ha to 8,339 ha. In contrast, the salt pans declined from 2,637 ha to approximately 303 ha (Fig. 2).

#### Environmental parameters of mangroves

***Freshwater flow***

The monthly freshwater discharge from the Dowlaiswaram dam from 1977 to 2011 averages

Table 1 — Godavari wetland features areas in ha

| CLASS | 1977 | 1988 | 2001 | 2008 | 2012 |
|---|---|---|---|---|---|
| Dense mangrove | 13636 | 14684 | 15554 | 14729 | 16394 |
| Sparse mangrove | 1388 | 1544 | 1858 | 2888 | 3300 |
| Degraded mangrove | 4510 | 3432 | 2317 | 1200 | 446 |
| Aquaculture | - | 1235 | 7948 | 8214 | 8339 |
| Beach | 3131 | 2153 | 1337 | 1579 | 1179 |
| Casuarina | 1244 | 1632 | 2166 | 2561 | 1576 |
| Mudflat | 3220 | 3659 | 2090 | 1799 | 2006 |
| Sand | 1141 | 801 | 485 | 1282 | 1899 |
| Upland | 35390 | 34931 | 30213 | 30135 | 31624 |
| Industries | - | 202 | 715 | 1687 | 1905 |
| Water | 8100 | 8099 | 7634 | 7617 | 7330 |
| Salt pan | 2637 | 2028 | 2078 | 704 | 303 |
| Total | 74400 | 74400 | 74400 | 74400 | 74400 |

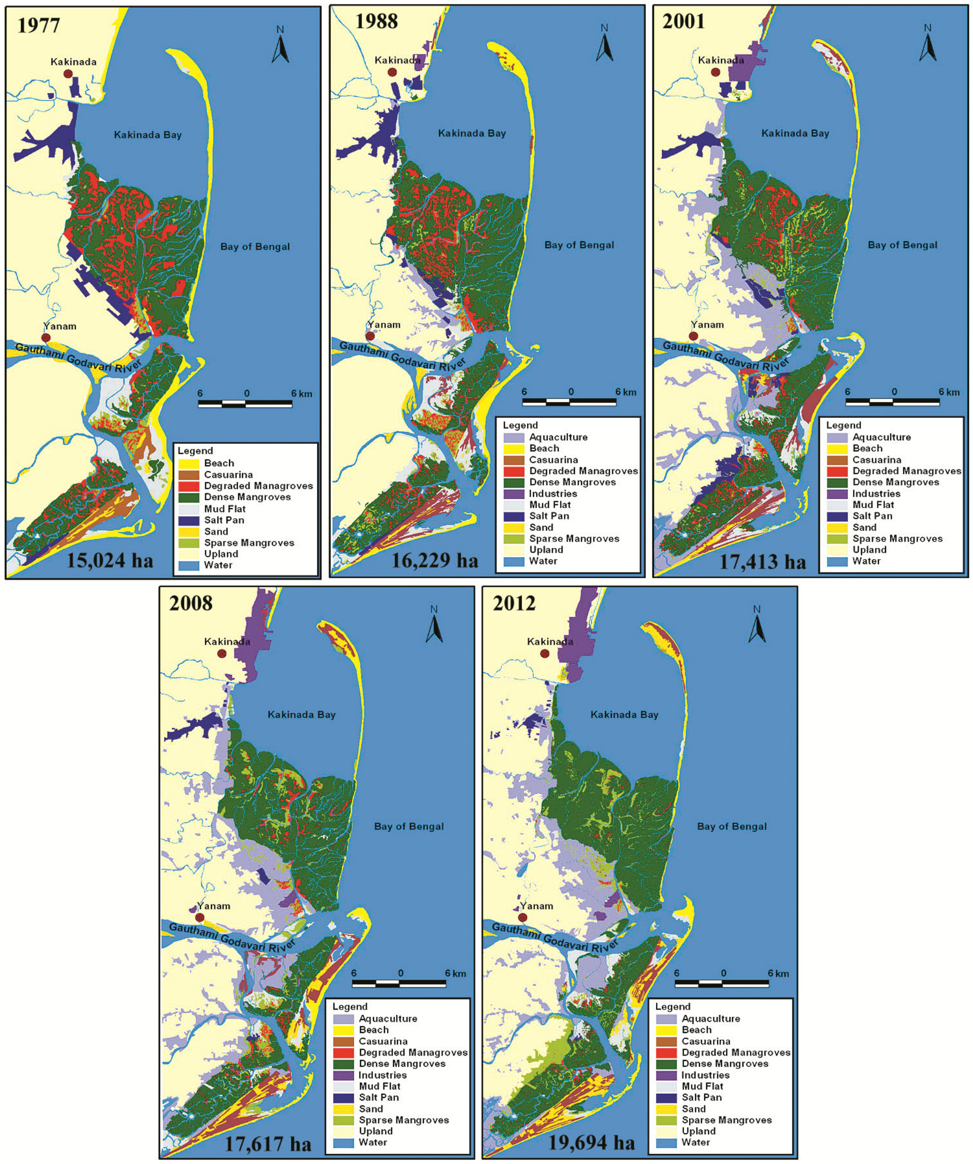


Fig. 2 — Mangrove wetland maps of 1977, 1988, 2001, 2008 and 2012

1,16,058 TMC. The freshwater flows into the Godavari delta mangroves for a six-month period and peak flow usually occurs between July and September (Fig. 3) when the entire delta is submerged. Brackish water conditions prevail from October to December and seawater dominates the entire mangrove wetland from January to June. The annual freshwater flow from 1977 to 2012 (Fig. 4) demonstrates that over the previous 35 years there has been an irregular discharge pattern.

***Rainfall***

Seasonal and annual rainfall data from the Kakinada meteorological station was analysed for the period 1977 to 2012. The analysis showed (Fig. 5) an increasing trend for rainfall in the winter when the highest rainfall of 116 cm and 128 cm occurred. Continuous rainfall occurred in all winter seasons between 1983 and 2011, except during the years 1993, 1999, 2000, 2006 and 2009. The summer rainfall indicates a one-time peak rainfall in 1990 of 3,617 mm. Rainfall during the South-West monsoon, which is the rainfall receiving Godavari periods, showed ordinary variations from 64,406 mm to 5,7,41,578 mm between 1977 and 2012. Rainfall during the North-East monsoon indicates no significant change over 35-years. The average annual rainfall curve (Fig. 6) shows that significantly variable rainfall during 1990 to 1998 and in 2010.

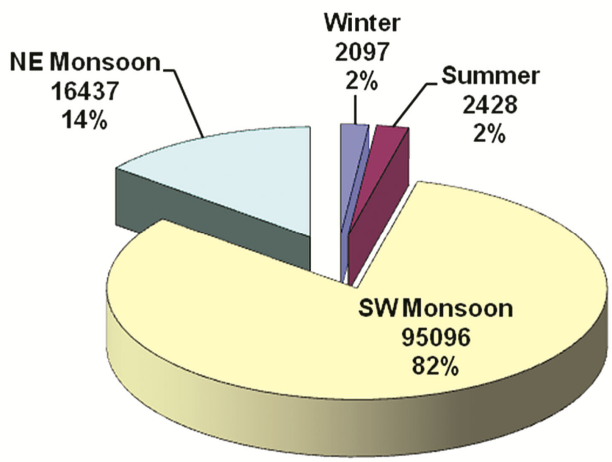


Fig. 3 — Seasonal freshwater flow (million cubic feet) from the Dowlaiswaram barrage

***Temperature***

The average annual temperature in the study area (Fig. 6) has been constantly increasing over the past 35 years from 21.78 ºC in 2007 to 33.60 ºC in 2011. Highest temperature was 34.91ºC (2009) and the minimum temperature was 21.78 ºC (2007). There was an increasing temperature trend from 1977 to 2011, with a rapid rise over the last 12 years.

**Social survey on awareness on mangroves**

In 39 mangrove-user villages, field surveys were conducted in which participants (Male: 55, Female: 24) were given a standard questionnaire and interactive discussions took place with participants to record the community's awareness of the mangrove's existence, species diversity, uses and current status. Most participants were aware of the various species,

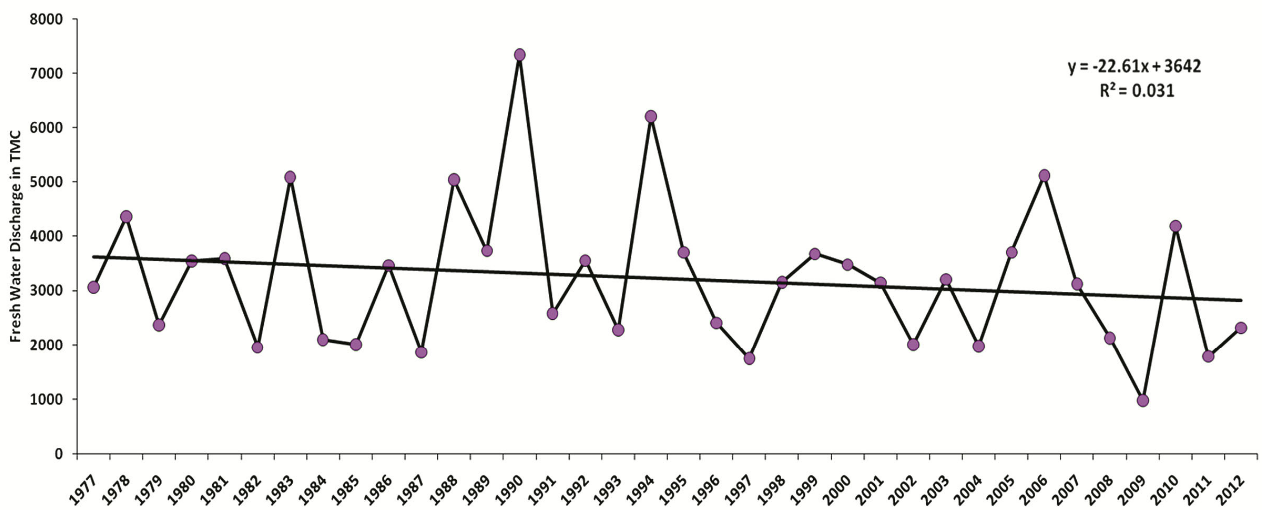


Fig. 4 — Annual freshwater flow from the Dowlaiswaram barrage

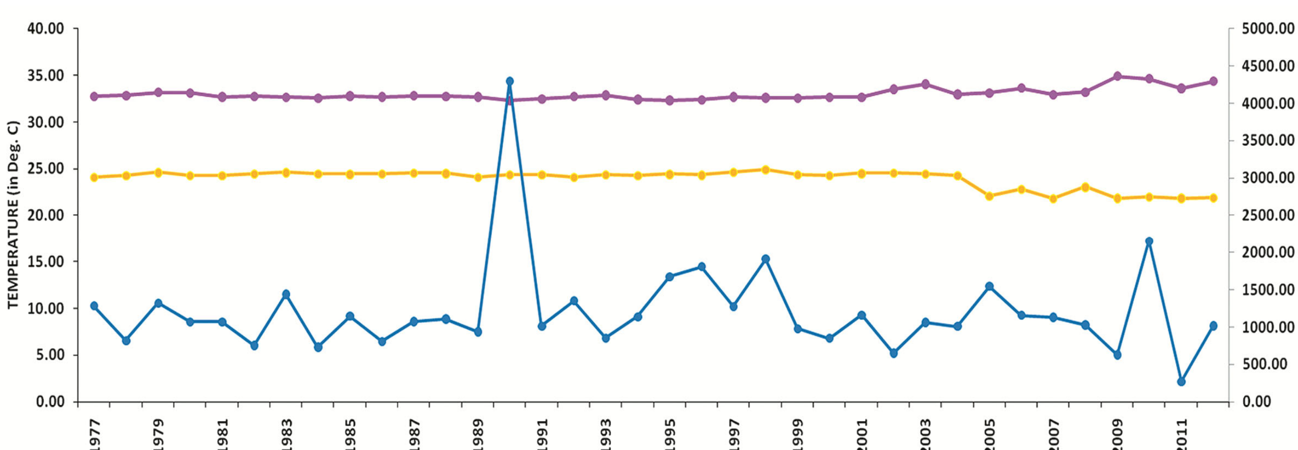


Fig. 5 — Annual rainfall and temperature of Godavari mangroves wetland

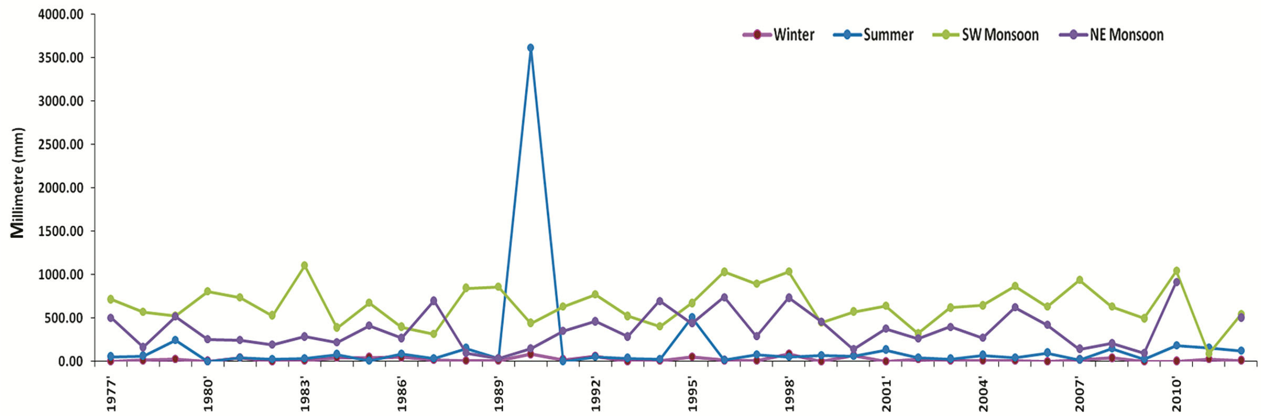


Fig. 6 — Seasonal rainfall of Godavari mangroves wetland

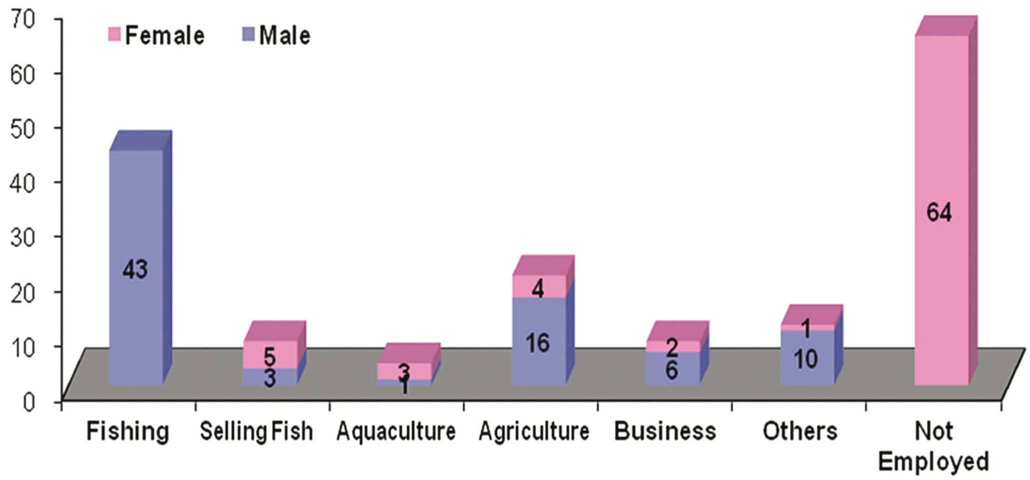


Fig. 7 — Local community employment

whereas a negligible percentage of people were unaware of mangrove species.

Fishing is the main occupation of the village population except Rayamerkay, Ramannapalem, Polukuru, Tallarevu and Gollakompalu (Fig. 7). Approximately 47 % of the male population depends on fishing, fish sales, 16 % do daily farming for their income, 16 % do other work such as business and take up monthly jobs and remaining 21 % are unemployed. Approximately 64 % of women in all villages are housewives. Approximately 8 % of the female populations are also engaged in the sale of fish and aquaculture, 4 % are engaged in agriculture, 3 % are engaged in businesses, such as the sale of milk and running small shops and 21 % are housewives.

For the people of Rayamerkay, Ramannapalem, Polukuru, Tallarevu and Gollakompalu, the monthly income is much higher compared to the other villages. This could be due to the people's major occupation, which includes agriculture and aquaculture in nearby wetlands. The rest of the villages, however, are traditional fishing communities that fish in the sea, creeks, canals, and mangrove wetlands. The fishermen in these villages have higher monthly income in the range of Rs. 2,000 to Rs. 3,000.

A pie diagram (Fig. 8) shows that 57 % of people feel that management, including restoration, participation of villagers in management, protection, and natural environmental changes such as rainfall and freshwater, are the main reasons for the increased mangrove areas. Approximately 37 % of people feel that the mangrove area has declined due to aquaculture, cattle grazing, illegal harvesting, consumption by local people and industrial growth, and 6 % have no knowledge of mangrove changes.

The local community has five major uses of mangroves. One is protection from natural hazards such as cyclone and tsunami; the second is the use of

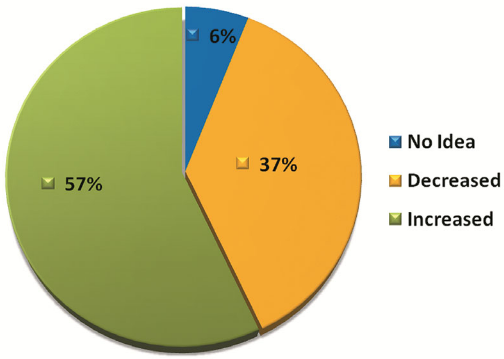


Fig. 8 — Local community perception

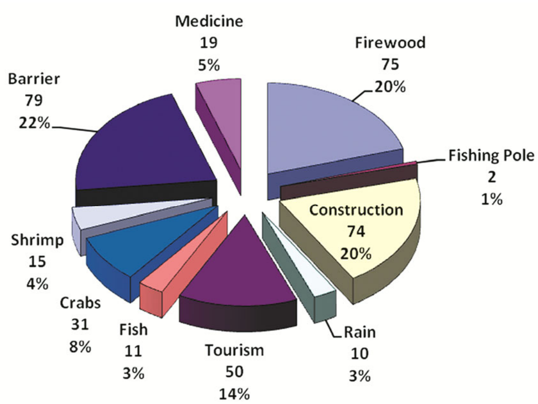


Fig. 9 — Uses of mangrove vegetation

firewood; the third is the use of wood for house-building; fourthly, mangroves serve as a nursery for fish, crabs and prawns, etc; and finally the mangroves can be used for tourism (Fig. 9). A few people mentioned other uses of mangroves, such as for collection of crabs, fish and shrimp; and their use for medicinal purposes and for fishing poles; and a few people felt that mangroves give rain. For the relief of stomach pain, nausea, toothache, fish and dog bites and other injuries, *Excoecaria agallocha* is mostly used as a medicine. The increase in mangrove area over the last 35 years, even after environmental and anthropogenic disturbances, could have been due not only to conservation and management activities but also due to increased citizen awareness of the value of protecting mangroves from logging and grazing which result in the destruction of mangroves.

## Discussion

#### Status of mangrove forest in Godavari in last 74 years

In 1977, the area of the Godavari mangrove vegetation was approximately 15,024 ha. At that time, the vegetation of the mangroves was only considered by authorities as marshy lands. As a consequence, local people removed huge areas of mangrove vegetation beginning in 1902 and from 1970 for income generation on a rotational basis under a coupe-system that created hypersaline conditions that affected natural regeneration[30]. The remote sensing data from 1988 (IRS 1C), revealed that the mangrove vegetation cover was about 16,229 ha (1988) with the area of mangrove cover further increased to 1,205 ha (15,024 ha), which was compared with Landsat TM satellite data of 1977. One study (Ramasubramanian *et al.*[26]) reported conservation and management efforts started in the mid-1980s, which made use of remote sensing techniques, which were found to be reliable tools and having many advantages to assist in mapping and monitoring of areal changes in mangroves. Analysis of the 2001 remote sensing data shows that the vegetation cover for mangroves increased from 16,229 ha in 1988 to 17,413 ha in 2001, but other land-use features were converted into aquaculture farms (Table 1). Research conducted by Ravishankar *et al.*[31] indicated that in 1999 stakeholders began successfully restoring the Godavari mangroves using remote sensing and with assistance from the local community. Unfortunately, fast development in shrimp farming began in 1988 in the Godavari that attracted local communities, leading in the conversion of mangrove vegetation and agricultural land resulting in mangrove degradation in the fringe regions[32]. Apart from shrimp farming, timber collection, livestock grazing and waste disposal also increased mangrove degradation. Moreover, natural occurrences such as hurricanes, severe river erosion flooding and accretion along the coast have also been implicated in the decline of mangroves in this area[31,33].

The increase in mangrove area from 17,617 ha to 19,694 ha from 2008-2012 increase was due to by the restoration of degraded mangroves by M S Swaminathan Research Foundation and the Forestry Department, Andhra Pradesh and the community of Andhra Pradesh. Further assessment demonstrates that during the last 14 years mangroves have been restored at a rate of 151 ha per year. Due to participatory management and restoration, it is expected that this process will continue, and by examining data from 2020, it can be predicted that the Godavari mangroves will have vegetation covering of 21,543 ha.

#### Influence of ecological parameters on mangroves over a period of 35 years

Environmental parameters such as rainfall, temperature, fresh water flow, soil, salinity, and tidal fluctuation are major factors influencing the extent, health, and diversity of mangroves. With regard to rainfall, the region's average annual rainfall shows a varying trend over the 35-year period thus, one possible cause of mangrove degradation in the late 1980s and early 1990s could also have been the irregular rainfall in the late 1970s-early 1980s. A similar study described the impact of rainfall on the distribution and composition of species in Vietnam[34]. The last 12 years have seen a rapid rise in temperature along the region. The IPCC has already predicted that temperatures in Asia will rise from 2 °C to 6 °C by 2100, in addition to rises in temperatures witnessed at higher latitudes, indicating that mangroves will expand into salt marsh habitat[35]. A study by Sandilyan[36] reported that rising temperatures in India will have an influence on species, and sea level rise will have a significant impact on mangrove forests. Tidal and freshwater flow exchange is an important factor in the expansion of mangrove vegetation[37]. The Gautami-Godavari River is the Godavari River's largest distributor that feeds the mangrove vegetation's freshwater and sediment requirements and this could assist in the further expansion of vegetation in an area.

## Conclusion

Godavari mangrove ecosystem, the second largest in India's East Coast for its flora and fauna, has been researched for a long time. In the present and in the future, they are of great importance and of immense value to humanity. Different variables, including human interference in the mid-1970s, degraded them. However, from the late 2000 onwards, mangrove vegetation cover showed a growing trend. This is attributable to the restoration and preservation measures taken in collaboration with M S Swaminathan Research Foundation and local community by the Forest Department, Andhra Pradesh. Godavari's mangrove wetland is anticipated to achieve maximum coverage in another 10 years with continuous restoration attempts, providing environmental variables, such as appropriate freshwater flow, availability of sediments, etc. are favourable for luxurious development of mangroves. The environmental analysis disclosed that information on climate variables over the last 35 years such as rainfall, temperature and freshwater flow, have assisted in improving the distribution and diversity of mangrove. Adequate freshwater flow, rainfall and low saline environments are directly proportional to the development of mangroves.

## Acknowledgments

The author is thankful to M. S. Swaminathan Research Foundation for providing necessary facilities for the research work.

## Conflict of Interest

The author declares that this research work contains no competing or conflict of interest.

## Ethical Statement

Hereby, I Dr. K. Jayakumar consciously assures that for the research article entitled “Spatio-temporal changes in the Godavari mangroves: A study examining land-use change and sustainable management” the following is fulfilled:

This is the authors' original research work, it has not previously been published or not currently being considered for publication anywhere. The article accurately and completely represents the authors' own research, analysis and results. All sources are correctly citied.

I agree with the above statements and certify that this contribution adheres to the standards stated in the Ethical Statement.

## References

1 Giri C, Recent Advancement in Mangrove Forests Mapping and Monitoring of the World Using Earth Observation Satellite Data, *Remote Sens*, 13 (4) (2021) p. 563.

2 Maurya K, Mahajan S & Chaube N, Remote Sensing Techniques: Map and monitoring of mangrove ecosystem – a review, *Complex Intell Syst*, 7 (2021) 2797-2818.

3 Strain E M A, Kompas T, Boxshall A, Kelvin J, Swearer S, *et al*., Assessing the coastal protection services of natural mangrove forests and artificial rock revetments, *Ecosyst Serv*, 55 (2022) p. 101429.

4 Hossain M S, Coastal Community Resilience Assessment: Using Analytical Hierarchy Process, In: *Climate Change Resilience by Mangrove Ecosystem*, edited by M. S. Hossain, (PRDI, Dhaka, Bangladesh), 2009, pp. 1-11.

5 Chan H T, Spalding M, Baba S, Kainuma M, Sarre A, *et al.* (Eds.), Tropical Forest Update, *A newsletter from the International Tropical Timber Organization to promote the conservation and sustainable development of tropical forests*, 21 (2) (2012) 1-24.

6 Vaiphasa C, Skidmore A K & De Boer W F, A post-classifier for mangrove mapping using ecological data, *ISPRS J Photogramm Remote Sens*, 61 (1) (2006) 1-10.

7 Srinivasa Kumar T, Mahendra R S, Nayak S, Radhakrishnan K & Sahu K C, Coastal Vulnerability Assessment for Orissa State, East Coast of India, *J Coast Res*, 26 (3) (2010) 523-534.

8 Gedan K B, Kirwan M L, Wolanski E, Barbier E B & Silliman B R, The present and future role of coastal wetland vegetation in protecting shorelines: answering recent challenges to the paradigm, *Clim Change*, 106 (2011) 7-29. https://doi.org/10.1007/s10584-010-0003-7

9 Space Applications Centre – ISRO, Coastal Zones of India (CZI), (Ahmedabad, Ministry of Environment and Forests, Government of India), 2012, pp. 609. https://mahenvis.nic.in/Pdf/Report/report_nrm1.pdf

10 Selvam V, Environmental classifications of mangrove wetlands of India, *Curr Sci*, 84 (6) (2003) 757-765.

11 Selvam V & Karunagaran V M, *Ecology and Biology of Mangroves - Orientation Guide*, (M. S. Swaminathan Research Foundation, Chennai, India), 2004, pp. 61.

12 Giesen W, Wulffraat S, Zieren M & Scholten L, *Mangrove Guidebook for Southeast Asia*, (FAO and Wetlands International, RAP Publication, Bangkok, Thailand), 2006, pp. 186.

13 Jayanthi M, Ravichandran P & Ponniah A G, *Status of Mangroves in relation to Brackishwater Aquaculture Development in Tamil Nadu*, (Central Institute of Brackishwater Aquaculture, Chennai), 21 (2010), pp. 34.

14 Van L H, Spalding M, Alongi D, Kainuma M, Clusener G M, *et al., Securing the Future of Mangroves, a Policy Brief*, (UNU-INWEH, UNESCO-MAB with ISME, ITTO, FAO, UNEP-WCMC and TNC), 2012, pp. 53.

15 Kathiresan K & Qasim S Z, *Biodiversity of Mangrove Ecosystem*, (Hindustan Publishing Corporation, New Delhi, India), 2005, pp. 251.

16 FAO, World Wide Web electronic publication, http://www.aquaculture.tn.nic.in/pdf/FAO%20Aqua41-79.pdf, version (2002).

17 Paez O F, The environmental impact of shrimp aquaculture: causes, effects, and mitigating alternatives, *J Environ Manage*, 28 (2001) 131-140. https://doi.org/10.1007/s002670010212

18 Dahdouh-Guebas F, Verheyden A, De Genst W, Hettiarachchi S & Koedam N, Four decade vegetation dynamics in Sri Lankan mangroves as detected from sequential aerial photography: a case study in Galle, *Bull Mar Sci*, 67 (2) (2000) 741-759.

19 Ramachandran S, Sundaramoorthy S, Krishnamoorthy R, Devasenapathy J & Thanikachalam M, Application of remote sensing and GIS to coastal wetland ecology of Tamil Nadu and Andaman and Nicobar group of islands with special reference to mangroves, *Curr Sci*, 75 (3) (1998) 236-244.

20 Mc Phearson P T & Wallace O C (eds), *Remote Sensing Applications to Biodiversity Conservation*, (Center for Biodiversity and Conservation of the American Museum of Natural History, New York), 2008, pp. 61.

21 Yang C, Everitt J H, Fletcher R S, Jensen R R & Mausel P W, Evaluating AISA + Hyperspectral Imagery for Mapping Black Mangrove along the South Texas Gulf Coast, *Photogramm Eng Remote Sens*, 75 (4) (2009) 425-435.

22 Satyanarayana B, Mohamad K A, Idris I F, Husain M L & Dahdouh-Gueba F, Assessment of mangrove vegetation based on remote sensing and ground-truth measurements at Tumpat, Kelantan Delta, East Coast of Peninsular Malaysia, *Int J Remote Sens*, 32 (6) (2011) 1635-1650.

23 Jayakumar K & Malarvannan S, An assessment of shoreline changes over the Northern Tamil Nadu Coast using open source based WebGIS techniques, *J Coast Conserv*, 20 (6) (2016) 477–487.

24 Jayakumar K, Selvam V & Prabavathy V R, A WebGIS-Based Study for Managing Mangroves of Godavari Wetland, Andhra Pradesh, India, *J Indian Soc Remote Sens*, 47 (2) (2019) 2027–2045.

25 German A J T, Radhika R S R, Dilip Kumar J & Sriganesh J, Assessment of wetland change dynamics of Chennai Coast, Tamil Nadu, India using satellite remote sensing, *Indian J Geo-Mar Sci*, 48 (08) (2019) 1258-1266.

26 Ramasubramanian R, Gnanappazham L, Ravishankar T & Navamuniyammal M, Mangroves of Godavari - analysis through remote sensing approach, *Wetl Ecol Manag*, 14 (1) (2006) 29-37.

27 Rahawarin Y, Gandhi Y, Hardiono M, Nugroho J & Manusawai J, Interpretation of Mangrove Ecosystem Dynamics in Bintuni Bay Nature Reserve Using Geographic Information System, *Biodiversitas*, 9 (2) (2008) 156-159.

28 Jayakumar K, Managing mangrove forests using open source-based WebGIS, In: *Coastal management: Global challenges and innovations*, edited by Krishnamurthy R R, Jonathan M P, Srinivasalu S & Glaeser B, (Candic Janco: Academic Press), 2019, 301–321.

29 Lillesand T, Kiefer R W & Chipman J, Remote Sensing and Image Interpretation, (John Wiley & Sons, New York), 2014, pp. 735.

30 Selvam V, Eganathan P, Karunagaran V M, Ravishankar T & Ramasubramanian R, *Mangrove Plants of Tamil Nadu*, (M S Swaminathan Research Foundation, Chennai, India), 2004, pp. 56.

31 Ravishankar T, Gnanappazham L, Ramasubramaniam R, Sridhar D, Navamuniyammal M, *et al*., *Atlas of Mangrove Wetlands of India, Part – II Andhra Pradesh*, (M S Swaminathan Research Foundation, Chennai, India), 2004, pp. 136.

32 Andhra Pradesh Remote Sensing Application Centre (APRSAC), *Environmental management and monitoring of shrimp culture project, East Godavari District, Andhra Pradesh – land use/land cover*, (Hyderabad, India), 1999.

33 ICMAM, *Critical Habitat Information System using GIS for Pichavaram mangroves, South India*, (Department of Ocean Development, Chennai), Technical report No. 4, 2001.

34 Hong P N & San H T, *Mangroves of Vietnam*, (IUCN, Bangkok, Thailand), 1993, pp. 173.

35 IPCC, *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change,* edited by Pachauri R K & Meyer L A, (IPCC, Geneva, Switzerland), 2014, pp. 151.

36 Sandilyan S, Impact of Climate Change on Indian Mangroves: A Review Paper, *Glob J Environ Res*, 8 (1) (2014) 1-10.

37 Hamilton L S & Snedaker S, Handbook for mangrove area management, In: *United Nations Environment Program and East West Center,* edited by Honolulu H I, (Environment and Policy Institute), 1984, pp. 123.