Dynamics of the Aquacultural Intensification in the Godavari-Krishna Inter Delta Region in India and Its Impact on Ecological Balance

T. V. Nagaraju, T. Rambabu, Sireesha Mantena, and B. M. Sunil

Abstract One of India's mega deltas, the Godavari-Krishna inter delta, has abundant natural resources that are good for the growth of agriculture. However, regional limitations are also rapidly giving way to aquaculture. In the coastal districts of Andhra Pradesh, particularly in the West Godavari and Krishna districts, aquaculture is one of the land feature classes that is expanding quickly. The other land cover elements, including vegetation and built-up areas, will be negatively impacted by aquaculture's unrestrained and indiscriminate expansion. Geographic information system (GIS) software was used to evaluate the dynamic changes in land use and land cover between 2013 and 2019. With the loss of about 650 square kilometers in both deltas, agricultural practices are changing to intensive aquaculture with an emphasis on increasing yields rather than lowering environmental quality. In the short period between 2013 and 2019, 16.5% of the agricultural land in the Godavari-Krishna delta was cleared to make way for infrastructure improvements and aquaculture. The essential components of the Godavari-Krishna delta aquaculture scenario are also highlighted in this research. The Godavari-Krishna delta is changing coastal ecology and is vividly depicted in this study.

Keywords Aquaculture · Coastal management · Environment · Remote sensing

T. V. Nagaraju (✉)
Department of Civil Engineering, S.R.K.R Engineering College, Bhimavaram, India
e-mail: varshith.varma@gmail.com

T. Rambabu
Water and Environment Technology (WET) Center, S.R.K.R Engineering College, Bhimavaram, India

S. Mantena
Department of Geo-Engineering, Andhra University, Visakhapatnam, India

B. M. Sunil
Department of Civil Engineering, National Institute of Technology Karnataka, Mangalore, India

1   Introduction

One of the agricultural and livestock industries with the most significant growth rate is aquaculture, which offers a potential means of enhancing livelihoods and food security and generating export income in Asian nations, including China, India, Bangladesh, and Vietnam [1]. India is one of the leading countries in producing and exporting aquatic products. The West Godavari district produces the most aquaculture in India and contributes considerably to export earnings [1, 2]. This area, which serves as the primary hub for aquaculture production in the state, makes a substantial contribution to the whole country's economy and regional and global food security. One-fourth of the state's aquaculture production in 2018 was produced by the West Godavari district alone [1]. The western Godavari delta region contributes significantly to the state's overall shrimp output, primarily raised in small, intense farming operations along significant waterways including Kolleru Lake, Yarracalava, Tammileru, and Ramileru. In 2019, the West Godavari district produced 11,52,201 tons of vannamei shrimp and fish across a total farming area of about 67,518 acres. Additionally, the new administration wants to make shrimp aquaculture, a significant business in the Godavari-Krishna inter delta, a vital economic sector. More specialized inputs and economies of scale are driving the development trend toward growing large-scale intensification. Diseconomies of scale, however, can also happen if a company becomes too big to operate effectively or through overcapitalization. Furthermore, farmers who lack sufficient capital are unable to access sources of livelihood capital or lack managerial skills would be unable to take advantage of such productivity advances because they face difficulties accessing capital or are being dominated by big input suppliers. Since shrimp output depends on a stable environment, expanding the production size also raises the chances for adverse environmental effects [3, 4]. Aquaculture development carries risks of adverse environmental effects, such as landform change, ecological degradation, loss of habitat, and nutrient enrichment, which can result in significant epidemics of shrimp disease [5, 6]. Despite the potential for high profits, employment opportunities, and increased exports to ensure better profits and food security, these benefits come at a cost. Rural households in the Godavari and Krishna delta do most small-scale shrimp farming [7].

There is already numerous research on land cover dynamics in river deltas, estuaries, and coastal areas utilizing remote sensing data. According to numerous studies of coastal areas and deltas, urban growth and human impacts caused agriculture and mangrove areas to shrink rapidly through time [8]. In contrast, urban surfaces, vegetated prawn fields, lakes, and ponds grew rapidly. Agricultural acreage declined dramatically in certain areas while growing in others. Because of the rapid developments in inland aquaculture cultivation, the Godavari delta in India and the Mekong delta in Vietnam have recently attracted the scientific community's interest [9, 10].

This study's primary objective is to list the most appealing characteristics of the Godavari-Krishna inter delta following the interconnection of the rivers Godavari and Krishna with the Pattiseema lift irrigation project. After the new state of Andhra

Pradesh was formed in 2014, geographical and temporal patterns of land use and land cover were observed in the Godavari-Krishna inter delta. The research was created to particularly accomplish the following goals: identify and map the main land cover/ land use classifications in the study area; (ii) collate the geographic and temporal distribution of the land cover/land use developments, and (iii) determine the scope and purpose of these modifications that occurred over these years. These results will be the foundation for assessing how the region's land use and cover have changed over time. In addition to providing a solid foundation for creating economic, social, and environmental policies to ensure sustainable development in the study region, this research will enhance the long-term knowledge about the causes and impacts of land cover/land use changes.

2 Godavari-Krishna Inter Delta

The study area, with a shoreline of about 88 km, Krishna District, was further separated into Krishna and West Godavari Districts in 1925. The study region included the Andhra Pradesh districts along the western and eastern deltas of the Godavari and Krishna rivers. About 6426.78 square kilometers are occupied by the West Godavari and Krishna inter delta, which is located between the latitudes of 16°56′15.63″ and 15°59′25.53″ N and the longitudes of 80°36′8.37″ and 81°52′31.35″ E. It is made up of 24 mandals in West Godavari and 31 mandals in Krishna District. The research area is situated between the Krishna and Godavari River deltas. Figure 1 displays the location of the present study's map. The climate is humid and hot, with summertime highs of up to 42 degrees Celsius. In summer, the mean daytime temperature is between 35 °C and 40 °C, whereas in winter, it ranges between 25 °C and 30 °C.

The western delta region of Andhra Pradesh is referred to as the "rice bowl" of the state since it produced most of the state's agricultural output overall and more than 50% of the export yields of rice during the early 1980s. It is one of the Andhra Pradesh coastal regions with the highest number of homes and agricultural fields; between 1970 and 1990, major natural disasters were experienced and resulted in severe damage. Due to its low elevation (between −1 and 5 m above sea level) and the significant tidal fluctuations caused by the Bay of Bengal, the Godavari and Krishna delta is a low-lying, flat area that is readily inundated. Since the 1990s, improvements in water resource management have decreased flood levels and created a favorable environment for aquaculture techniques.

Before the white spot syndrome virus (WSSV) epidemic hit the aquaculture industry in 1994, Penaeus monodon had been raised on farms since 1990 with stocking numbers of 20,000 shrimp/acre. As a result, the area used for aquaculture production shrunk dramatically, and the sector nearly died. With a maximum legal stocking density of 1 lakh shrimp/acre, the Government of India permitted the specialized pathogen-free Penaeus vannamei culture to restart the sector in 2009. Aquaculture exports from Andhra Pradesh were worth Rs. 2,100 crores in 2009–10; this amount rose to Rs. 14,000 crores in 2014–15. Andhra Pradesh had the most
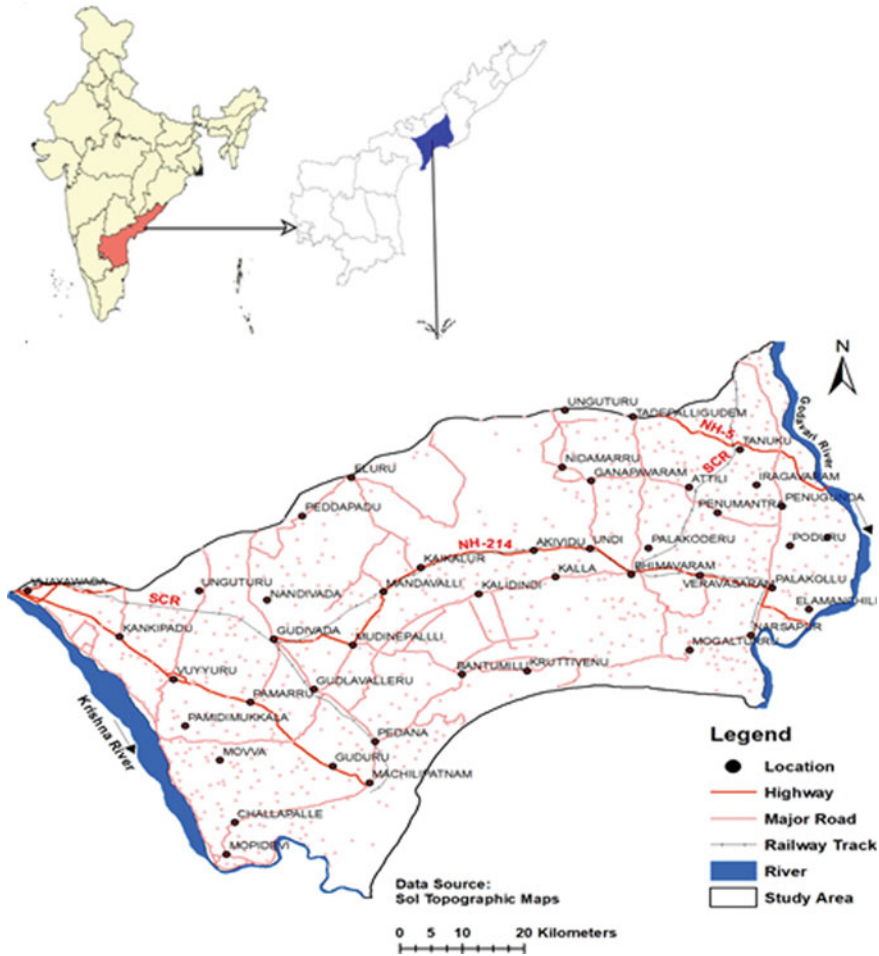
Fig. 1 Godavari-Krishna inter delta

outstanding production value in 2019 with 44,856 crores, of which 11,519 crores were attributable to exports from the Godavari delta alone [1]. With 1.323 lakh ha, the Godavari-Krishna inter delta is the state's largest aquaculture production area.

3 Methodology

A land use and land cover categorization feature goal are to make it possible to arrange/group the variety of information that is readily available into a helpful framework. Along with systematic inventory and mapping, land use information from

satellites and other sources is also included. The created framework for classifying land use and land cover lends itself to remote sensing-based mapping. The National Remote Sensing (NRSC) Agency's classification scheme is used in this study [11]. Level-I, Level-II, and level-II classifications of land use and land cover are described in the classification. Level-II provides a semi-detailed breakdown of information for the catch-wide class, whereas Level-l provides a broad categorization of several land use classes. Some Level-I classes still have a more acceptable level separation of units in the third-level groups. We fulfill the minimal data requirements for the 1:20,000 scale mapping. Visual interpretation techniques have been used to map the study area's land use and cover. Visual interpretation techniques have been used to map the study area's land use and cover. Using satellite data from the Kharif and Rabi seasons, the land use/land cover features have been identified and mapped based on image attributes. Additionally, various reports and maps pertaining to land use and land cover were used in creating the land use and land cover maps. Field observations about cropping patterns, changes in land use and land cover, and sample images are also acquired in order to physically verify the doubtful areas or hotspots caused by similar spectral responses and spectral fingerprints.

4   Land Use and Land Cover Results

4.1   Land Use and Land Cover Classification and Detection

In 2014, before and after state bifurcation, Figs. 2 and 3 display the surface distribution (in km^2) and evolution of the fraction of each land cover/land use class. Over the past 50 years, cultivated lands have remained the dominant land cover in the area. In the research area, aquaculture ponds made up the second-highest land cover. Trends can be seen in the land cover classes changing the most between 2013 and 2019, mainly cropland and aquaculture ponds. Due to the active involvement of the Patiseema lift irrigation project connecting the rivers Godavari and Krishna, bare lands have significantly diminished in recent years. Throughout the study period, built-up areas and aquaculture ponds developed dramatically and steadily. In the inter delta region, agricultural lands altered during all the studied years, primarily due to the increase of aquaculture ponds. During the study period, it was particularly evident in the east and west catchments of the Upputeru and Undi canals that agricultural lands were being drastically converted into aquaculture grounds.

Table 1 displays the specific dynamics of the changing land use and covers the research area. The table displays the conversion of one class to another because of the cross-tabulation matrix of the land cover/land use change. For instance, while considering the entire study period of 2013–2019, the agricultural land covering area varied from 4601.74 km^2 in 2013 to 3948.77 km^2 in 2019, when it eventually began to decline. Figure 4 makes it easy to see how agriculture is dynamic. Aquaculture is the most prevalent land use class in the region after agriculture. Aquaculture is
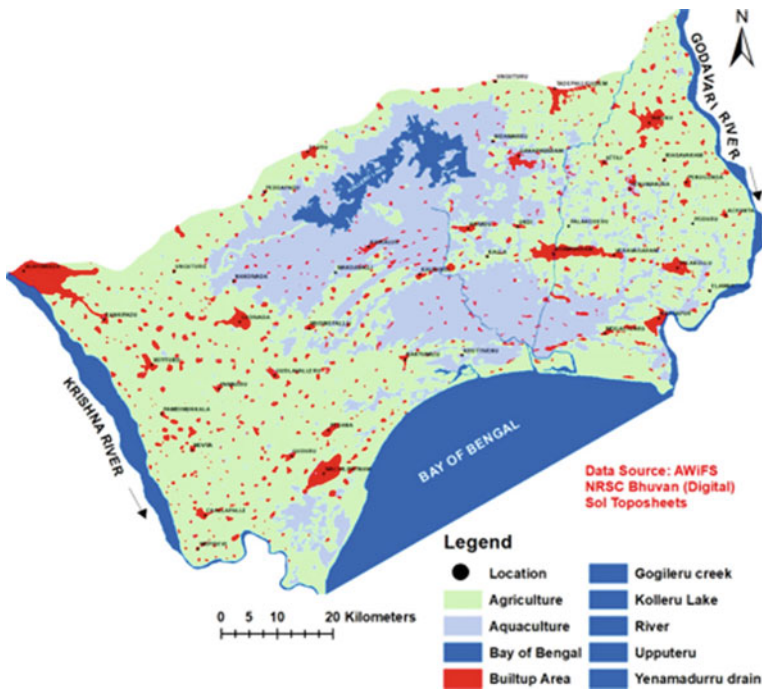
Fig. 2 Land use and land cover in 2013

not very advanced in the research region. Most of the area's significant drainage systems are covered by it. Figure 4 displays the variances in the aquaculture land coverage area. Initially covering 1279.18 km^2 in 2013, the aquaculture coverage area continued to grow till it ultimately covered 1892.80 km^2 by the end of 2019.

4.2 Potential Drivers of Aquaculture Land Cover in the Godavari-Krishna Inter Delta

The study region's principal water resources are the Godavari River, Krishna River, Kolleru Lake, Upputeru River, Yanamaduru Drain, and Gogilleru Creek (see Fig. 5). One of the most significant fresh waters in the country is Kolleru Lake, which is situated between the Krishna and Godavari Rivers deltas. The two most significant streams that flow into the lake are Guvaleru and Tammileru. In addition, irrigation channels and drains feed the lake. The river Upputeru is the lake's only exit. The remote sensing-based analysis shows that aquaculture pond development and converting productive agricultural land to aquaculture disturb Kolleru Lake and its surroundings.
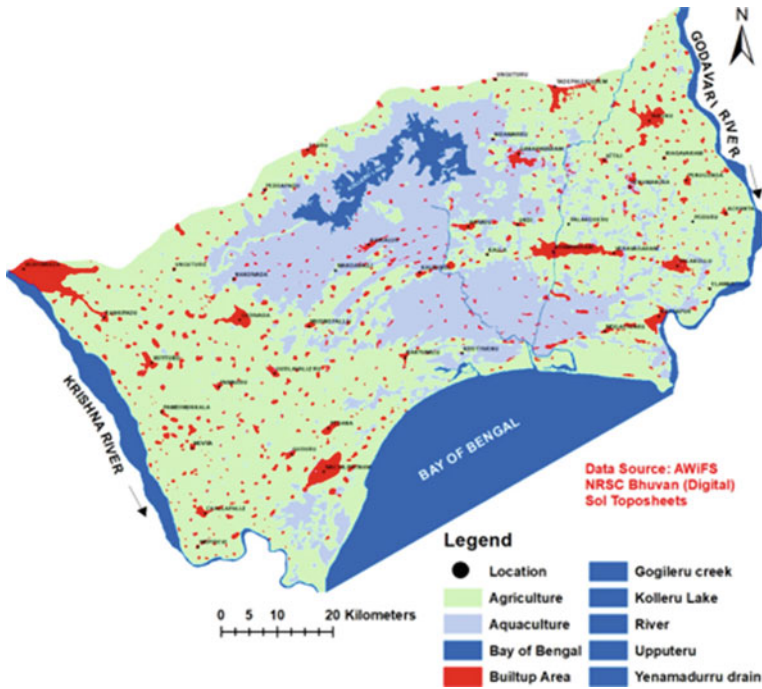
Fig. 3 Land use and land cover in 2019

Table 1 Land use and land cover classes in the study area

Class	Area (km²) in the year				
	2013	2015	2016	2018	2019
Aquaculture	1279.18	1325.65	1432.75	1797.09	1892.80
Built-up area	293.86	311.61	347.04	395.09	396.18
Agriculture	4601.74	4539.57	4424.69	4042.26	3948.77
Others	251.99	249.95	222.30	192.34	189.04
Total	6426.77	6426.78	6426.77	6426.77	6426.78

The favorable government policies, the salt encroachment issue, and the commercial dimension are the leading causes of this transformation. The presence of a higher concentration of saline waters in the study area is due to the plain, low-lying area's extensive network of rivers and canals, the Bay of Bengal's strong tides, the pumping of saline waters from deep aquifers for shrimp culture, and the rising sea levels. Additionally, paddy farming revenue 14 times less per crop than shrimp culture (four months). Moreover, in the current intensive inland aquaculture context, engineered aquaculture components are crucial to reducing pollution load. Rich in
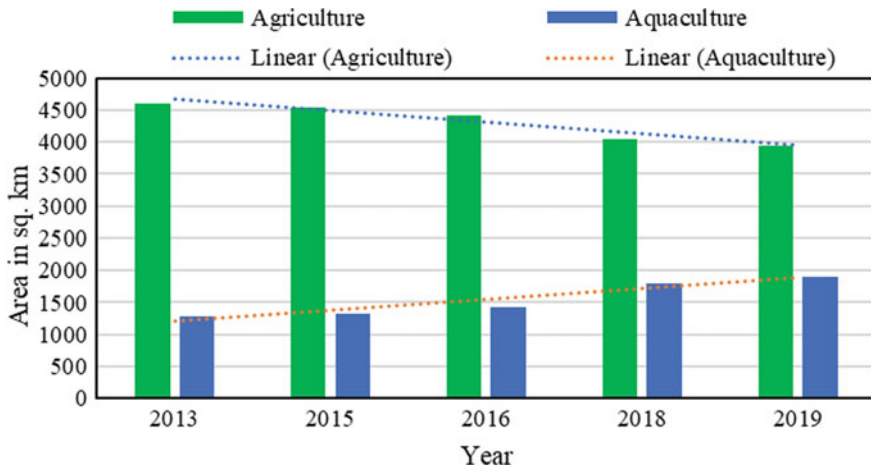
Fig. 4 Land use and land cover trend of agriculture and aquaculture

Fig. 5 Water resource map of Godavari-Krishna delta

nutrients, treated effluent can be used to crops as fertilizer and promote sustainable environment and energy nexus.

The Godavari-Krishna inter delta has suffered significant harm due to climate change, environmental degradation, economic growth, and rapid population growth. The implications on biodiversity and ecological changes include rising sea levels,

severe storms, and typhoons, flooding during the wet seasons, salinity intrusion during the dry seasons, a lack of fresh water for home and agricultural use, an alkaline environment, and contaminated water. The dynamics of intensive aquaculture have been noticed and analyzed in this research study and are presumed to be a result of all the variables.

5   Conclusions

This study aims to fill a critical gap to assess the dynamics of LULC in South Asia's massive Godavari-Krishna inter delta. Findings from the current study showed that between 2013 and 2019, Andhra Pradesh's inter delta experienced significant land changes. In comparison to the Krishna delta, the Godavari delta has seen more haphazard growth in human settlements, increasing by 100 km^2 between 2013 and 2019. It may result in the depletion of natural resources and lower-than-average living standards.

The significant growth of intensive aquaculture ponds, particularly along the catchments of Kolleru Lake, Upputeru River, Yanamaduru Drain, and Gogilleru Creek, is most noteworthy. The aquaculture area exhibits tremendous expansion, with 32.4% from 2013 to 2019. The unique expansion of aquaculture can be seen in lake Kolleru's periphery and in the fertile deltaic soils that support prawn farming. In addition to the salinization of soils, this causes a considerable loss of water quality in the deltaic environment. It might affect soil production and result in food-based drought situations.

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