Coastal erosion and habitat loss along the Godavari delta front – a fallout of dam construction(?)

B. Hema Malini and K. Nageswara Rao*

Department of Geography and *Department of Geo-Engineering, Andhra University, Visakhapatnam 530 003, India

Analysis of multi-date satellite sensor data and maps indicated loss of 1836 ha of land during 1976–2001 along the Godavari deltaic coast resulting in displacement of coastal communities and mangrove destruction. Decrease in sediment loads from an annual average of 145.26 million tons in 1971–79 to 56.76 million tons during 1990–98, apparently due to construction of dams, largely diminished vertical accretion at the delta, while continued coastal subsidence that might have been accentuated by possible neotectonic activity and consequent relative sea level rise led to shoreline retreat. The extant conditions indicate that the problem may compound in future causing irreparable damage to this important deltaic ecosystem.

COASTAL erosion has been one of the major environmental concerns in many parts of the world. The situation is particularly serious in the deltaic regions due to construction of dams in the river basin that impede sediment supply at the river mouths as a result of which the rates of subsidence and sea level rise may exceed rates of vertical accretion leading to erosion of coastal lands\(^1\). In India, delta ecosystems that are considered as cradles of civilization have significant economic importance in terms of agriculture, water resources, wetlands, wildlife habitats, fish production and tourism. For instance, the Godavari delta, which is termed as the rice bowl of Andhra Pradesh, is one of the major prograding deltas on the east coast of India bordering the Bay of Bengal and is a densely populated zone of intense economic activity. Fed by a large 312,812 km\(^2\) drainage basin, the delta of this second longest river (1465 km) in the country spreads over an area of about 5100 km\(^2\). As evident from the presence of relict beach ridges far inland from the present shoreline, the delta advanced into the sea by sustained deposition during the past 5 to 6 thousands of years\(^2,3\). As a result, the seaward bulge of the delta overlaps the continental shelf across by about 30–35 km (Figure 1) when compared to the general trend of the east coast. Several studies on the nature of coastal landforms along the delta front also indicated increased sedimentation rates through the river during the nineteenth century and even over a major part of the twentieth century. Mahadevan and Prasada Rao\(^4\) based on an analysis of multi-date maps spread over a period of 100 years traced the growth of a 21-km long sand spit at the delta, east of Kakinada that began around AD 1850 and reached more or less the present shape by the 1958 owing to increased sediment supply from the catchment due to deforestation. Sambasiva Rao and Vaidyanadan\(^5\) reported overall cumulative accretion of land due to development of several other sand spits at the distributary mouths of the Godavari during the period between 1937 and 1977, based on the study of toposheets (1937), aerial photographs (1968) and field mapping (1977). However, a recent field study\(^6\) revealed predominance of erosion rather than deposition along the estuarine banks and delta front shoreline. Similarly, field observations by us during 1999–2002 also revealed pronounced erosion at certain sections of the deltaic coast due to which even some villages were to be evacuated. In this background, it is essential to understand the magnitude of, and the factors responsible for, the degradation of this important coastal ecosystem in the country. The present study is such an attempt in this direction.

Figure 1. Map showing location of the Godavari delta highlighting the seaward bulge of the delta with stippled pattern (generalized from Sambasiva Rao and Vaidyanadan\(^2\) and Nageswara Rao et al.\(^7\)). The river mouth areas enclosed by rectangles are enlarged in Figure 2a, b and c.
Materials and methods

Four sets of satellite sensor data are used in this study. They are (i) IRS 1B LISS-II imagery of path 26 and row 56, dated 5 January 1992; (ii) IRS 1C LISS-III image of path 103, row 61, dated 29 May 1997; (iii) IRS 1C LISS-III image of path 103, row 61, dated 27 March 1999; and (iv) IRS 1D LISS-III imagery of paths 103 & 104, row 61, dated 6 February 2001. All the images are georeferenced with the topographic maps of 1976 on 1 : 50000 scale for comparison using ERDAS 8.5 software. The temporal changes along the delta front coast are analysed by overlaying the four satellite datasets with reference to one another as well as with the corresponding topographic maps. The areas of deposition and erosion in between every two consecutive dates for all the five datasets (including the 1976 base data of topographic maps) are identified. The area statistics for the zones of erosion and deposition are obtained by query method using ArcGIS 8.3 software. The entire 160 km long delta front shoreline was examined to demarcate the zones of erosion and deposition. The areas around the mouths of the three distributaries, Nilarevu, Gautami and Vasishta where significant changes occurred during the period are separately mapped, highlighting the zones of erosion and deposition at each.

The sea level data recorded at Visakhapatnam and Chennai ports during the period from 1970 to 1996, available from the Permanent Service for Mean Sea Level (PSMSL) website were obtained and the trends in sea levels were plotted. Similarly, the daily tide gauge data recorded at Kakinada port over a 12-year period during 1990–2001 were obtained from the tide tables published by the Survey of India and the annual mean sea levels for Kakinada were computed.

Data on the suspended sediment loads recorded at Polavaram river gauging station located at about 30 km upstream of the delta apex were obtained for the period from 1971 to 1998 from the records of the Central Water Commission and the annual and decadal trends in the sediment loads are plotted.

Results

Coastal erosion

The four sets of satellite sensor data pertaining to the recent years from 1992 to 2001 in conjunction with the topographic maps of the 1976 of the Godavari delta region revealed conspicuous shoreline changes, especially at the distributary mouths of Nilarevu, Gautami and Vasishta. There is no discernible change at the mouth of the fourth distributary, i.e. Vainateyam.

The shore zone near the mouth of Nilarevu, which is the terminal branch of the Gautami in the northern part of the delta front coast, is subjected to spectacular change during the period under study. As shown in Figure 2a, Nilarevu mouth experienced significant widening by 1992 when compared to its width in 1976. Similarly, the shoreline to the north of the mouth also receded landward. Although there has been some deposition to the south of the
Nilarevu mouth, erosion is dominant especially along the shoreline north of the mouth during the 25-year period under study. In fact, mangrove vegetation that was sheltered behind the sand spit in 1976 at the northern side of the mouth is directly exposed to open wave attack in the area at present (Figure 3a).

The coastal zone at the mouth of the southern branch of Gautami is no exception. In 1976, there were two prominent spits grown into the sea at oblique angles on both sides of the Gautami mouth as can be seen in the topographic map of the area in 1976 (Figure 2b). By 1992, however, almost the entire spit to the north of the mouth was eroded. The same trend of erosion continued further through 1997, 1999 and 2001 on the northern side, while there was some deposition to the south of the mouth.

The condition at Vasishta mouth is much more severe. In 1976, the western margin of the Vasishta mouth was extended much further into the sea when compared to its eastern margin. By 1992, however, the shoreline to the west of the mouth receded landward by almost 2 km across due to pronounced erosion (Figure 2c). As a result, Biyyapatippa village, which was almost 2 km behind the shoreline in 1976, was destroyed and, as the field observations in 1999 revealed, the entire village was evacuated and people rehabilitated elsewhere further inland. Although a small barrier island developed between 1992 and 1997 on the western side, erosion continued as a result of which another village namely Chinamailavanilanka located further west was also subjected to this erosion (Figure 3b). The barrier island migrated landward by 1999 and 2001. But erosion seems to have continued in the area, especially along the shoreline to the west of the mouth.

The data on the extents of shoreline change at the three mouths put together indicated that an area of about 2030 ha was eroded during the 16-year period between 1976 and 1992, while deposition accounted for 1091 ha resulting in a net loss of 939 ha. The trend continued throughout the 25-year period from 1976 to 2001, leading to the loss of land by about 3516 ha, which is more than double the area gained by deposition. There was a net loss of 1800 ha of land in 25 years at an average rate of 72 ha per year right at the river mouths. Similarly, when the entire 160 km long deltaic coast is considered, erosion is found to be dominant along as much as 102 km, while deposition is limited to the rest of 48 km coastal section only. The area statistic for the entire Godavari delta revealed that the area lost due to erosion was 4803 ha, while the addition of land by deposition was only 2967 ha during the 25-year period, indicating a net loss of 1836 ha at a rate of 73.44 ha per year (Table 1).

### Sea levels

Data on sea levels at Visakhapatnam and Chennai for the period from 1970 to 1996 do not indicate any rise in sea level. However, annual sea level trends at Kakinada calculated from the daily tide gauge data indicated a slight upward trend during 1990–2001. This localized rise in sea level, if any, may be considered as the result of land subsidence at the Godavari delta. It is known that compaction of sediments at deltas could lead to land subsidence and relative sea level rise. Such a phenomenon occurs when a distributary mouth is shifted from one location to another along the delta coast leading to shoreline retreat at the abandoned distributary mouth. Agrawal and Mitra observed that in the abandoned part of the lower

### Table 1. Data on areal extent of erosion and deposition along the entire 160 km stretch of the Godavari delta front coast

<table>
<thead>
<tr>
<th>Period</th>
<th>Erosion (ha)</th>
<th>Deposition (ha)</th>
<th>Net loss (ha)</th>
<th>Rate of loss (ha/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1976–92</td>
<td>3014</td>
<td>1950</td>
<td>1064</td>
<td>66.5</td>
</tr>
<tr>
<td>1992–97</td>
<td>982</td>
<td>495</td>
<td>487</td>
<td>97.4</td>
</tr>
<tr>
<td>1997–99</td>
<td>378</td>
<td>242</td>
<td>136</td>
<td>68.0</td>
</tr>
<tr>
<td>1999–2001</td>
<td>429</td>
<td>280</td>
<td>149</td>
<td>74.5</td>
</tr>
<tr>
<td>Total – 25 years</td>
<td>4803</td>
<td>2967</td>
<td>1836</td>
<td>73.44</td>
</tr>
</tbody>
</table>
Ganges delta plain, a transgressive stage has resulted due to lack of sediment supply from the river while at the mouth of the Padma and Hoogly with active progradation, regressive stage is present. Neotectonic activity can also cause land subsidence resulting in relative sea level rise and shoreline retreat. A major fault has been inferred based on aerial photographic study\textsuperscript{2,10}, extending ENE–WSW about 10 to 15 km inland from Narsapur up to Nilarevu estuary, along which three distributaries of the Godavari, namely, Vasishta, Vainateyam and Gautami exhibit anomalous meandering. Rengamannar and Pradhan\textsuperscript{11} reported that drill hole data of the Oil and Natural Gas Corporation (ONGC) on both sides of this lineament indicated displacement of Tertiaries at depth, although there is no visible evidence on the ground. Sastry et al.\textsuperscript{12} observed that the Godavari delta is prograding into a microtidal and low to moderate wave environment. Referring to earlier studies, Sastry et al.\textsuperscript{12} stated that the growth of the 21-km sand spit east of Kakinada led to erosion along the northeastern end of the Godavari delta coast at Uppada village as the sediment transport along the main coast in the Kakinada Bay and further north towards Uppada was cut-off, the major portion of the sediment supply being utilized for the growth of the spit. They observed that even in low wave energy environment, the delicate forms of sedimentary jetties tend to be modified as soon as reduced distributary outflow and diminished sediment yield bring the process of prolongation to an end. They also mentioned that if the sediments brought by the river is no longer active, then the delta becomes inactive and will be quickly attacked by the sea. This implies that coastal erosion at the deltas might be triggered due to reduction in sediment input by the rivers. Hence it is worth considering the trends in sediment loads of the Godavari.

**Sediment loads**

According to an estimate by Milliman and Meade\textsuperscript{13}, annual average suspended sediment load of the Godavari River is about 96 million tons. However, Chandramohan et al.\textsuperscript{14} reported that the sediment load issued into the sea by Godavari river in the year 1984 was about 38.8 million tons only. An analysis of the data on sediment loads that were collected in the present study from the river gauging station at Polavaram located at about 30 km upstream of Rajahmundry indicated a phenomenal decrease in sediment loads of the river during a 28-year period from 1971 to 1998. The annual sediment loads during the period were highly variable ranging from a maximum of 271.66 million tons (MT) recorded in 1976 and a minimum of 19.50 MT in 1987 at an annual average of 97.47 MT. There was a considerable downward trend in the sediment loads in the river during the period as revealed in Figure 4a. The decadal averages also indicated a progressive decrease in the levels of the sediment loads from 145.26 MT during 1971–79 to 87.35 MT and 56.76 MT, respectively, in the subsequent two decades (Figure 4b). Apparently, decrease in sediment loads of that magnitude in the downstream sections of the river is due to construction of dams in the catchment. According to a report by the Ministry of Water Resources\textsuperscript{15}, New Delhi the live water storage capacity in the Godavari basin has increased from a mere 1.6 km\textsuperscript{3} to as much as 19.5 km\textsuperscript{3} during the post-Independence period due to construction of a number of dams. Besides, an additional storage of about 18.8 km\textsuperscript{3} is expected once the dams, which are either under construction or being contemplated, are put in place.

**Discussion**

It is generally presumed that deltas sustain only when the coastal subsidence that occur due to subsurface fluid withdrawals and oxidation of drained soils is balanced by the continued vertical accretion of the riverine sediment\textsuperscript{1}. If the sediment supply through the river is diminished, the subsidence, which however continues, leads to relative sea level rise causing land erosion. A number of studies on deltas elsewhere indicated that construction of dams affect the sediment influx, thereby leading to coastal erosion as, for instance, at the deltas of Mississippi, Rhone and Ebro\textsuperscript{1}, Nile delta\textsuperscript{16}, Volga delta\textsuperscript{17} and along the Texas Gulf coast in USA\textsuperscript{18}. Similar conditions appear to prevail in the Godavari delta system as well. Although earlier studies\textsuperscript{2,10,11} suggested neotectonic activity in the Godavari delta region, the delta front shoreline had experienced progradation even during the earlier part of the twentieth century as reported by Sambasiva Rao and Vaidyanadhan\textsuperscript{5}. It is hard to believe that there has been any intensification of neotectonic activity during the last two to three decades to cause pronounced erosion that was not noticed in earlier studies. Therefore, reduction in sediment supply at the delta, probably due to construction of dams across Godavari and its tributaries in the catchment during the recent decades might be the major cause for the shoreline erosion as continued subsidence could lead to relative sea level rise. The coastal subsidence might have been compounded due to neotectonic activity, if any. The widening of Nilarevu estuary, pronounced erosion along most part of the delta front coast and consequent shoreline recession causing loss of mangroves and human habitations are indicative of the increased landward reach of marine activity. Although the stochastic incidence of cyclones and the associated tidal surges might be responsible for episodic severe erosion along the east coast, as pointed out by Mascarenhas\textsuperscript{19}, the apparently sustained erosion, as revealed in the present study could be due to significant decrease in sediment supply. Thus the balance of evidence indicates that construction of dams across the river and its tributaries might be the main reason for the recent widespread erosion at the delta and, as things stand, erosion would continue leading to loss of fertile coastal lands and displacement of coastal communities, besides loss of bio-
diversity due to mangrove destruction. While construction of dams across rivers is unarguably necessary for irrigation and electricity generation, there should be adequate provision for letting water through the downstream courses at least during peak flows so that dams are not starved of the much needed sediment inputs for coastal stability. Similarly, remobilization of sediments that are currently trapped in reservoirs may also be accomplished through appropriate engineering methods, which would have a double benefit of maintaining the reservoir capacity as well as sediment budget at the deltas. Such provisions in regulating the rivers would ensure the health of delta ecosystems and thereby the well being of the coastal communities, besides adequate protection of biodiversity, which is considered as the basis of continuous evolution of life forms and in turn maintaining the life-sustaining systems of the biosphere.

Conclusion

Sustained erosion at the Godavari delta for the past two and a half decades claimed about 18.36 km² of coastal land, leading to displacement of coastal communities and loss of mangrove vegetation. Apparently, decreased sediment supply through the river caused relative sea level rise under continued coastal subsidence along the delta front region. The extant conditions indicate that the problem may compound in future as more dams are coming up across the river.


ACKNOWLEDGEMENTS. We are grateful to the Department of Ocean Development for financial support through a research project (DOD/25/IOGBP/LOICZ/1/95) during 1998–2002, which helped us to take up this study. We thank the officials of the Central Water Commission, Hyderabad office for providing us with data on sediment loads. Thanks are also due to the referees for valuable information, comments and suggestions. 

Received 22 March 2004; revised accepted 7 June 2004