

GEOMATICS ANALYSIS OF THE IMPACT OF PREDICTED SEA-LEVEL RISE ON THE AGRICULTURE ALONG THE COASTAL ZONE OF ANDHRA PRADESH

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ABSTRACT:

Global warming induces steric as well as eustatic rise in sea-level, by thermal expansion and addition of ice-melt water, respectively. Although the IPCC (2007) estimated a maximum possible sea-level rise of about 59 cm, more recent estimates show a global average rise of 1 m by the 2100 AD. Geomatics-based predictive models on the possible impact of sea-level rise on the agriculture in the coastal regions are necessary to initiate appropriate mitigation plans. The present study is an attempt in this direction taking the Andhra Pradesh (AP) coast as an example. The land use / land cover pattern of the AP coastal zone was mapped through the interpretation of IRS LISS III imagery from 2008. SRTM digital elevation models have been used to interpolate contours at 1 m interval for the entire coastal region. The irregularities in the contours thus interpolated were corrected using the landform maps based on the disposition of the beach ridges, mudflats, etc. Even when IPCC (2007) estimates of 0.6 m rise in sea level are considered, the area within 2.1 m elevation would be affected by the sea-level rise by the 2100 AD along the AP coast since the spring high tide level in the region is 1.5 m. Based on this premise, the impact of the predicted sea-level rise on the agriculture in the AP coastal zone is extracted by overlaying the 2.1 m contour on the land use / land cover map of the region. The study revealed that an area of 1906 km² lie in the present intertidal zone of which aquaculture occupy over 231 km², followed by salt pans which occupy about 96 km², while the remaining area exhibits mangrove forests, lagoons, mudflats, tidal creeks, etc. If the sea-level rises by ~0.6 m (as predicted by IPCC, 2007), the high-tide line shifts landward up to the present 2.1 m elevation affecting the land use /land cover in an additional area of 1233 km² area between the present and future high tide lines. At present, aquaculture occupy 499 km², salt pans of 136 km², paddy crop occupy about 319 km², plantations occupy about 279 km² in this region all of which would be affected by the sea-level rise. On the whole, an area of 3139 km² including all the present intertidal wetland ecosystems as well as the area between the present and future high tide lines would be affected along the entire 1030-km-long AP coast threatening about 1.29 million people, besides all their economic activities including agriculture, in 282 revenue villages, if the sea-level rises even by about 0.6 m. The low-lying Krishna-Godavari delta region in the central part of the AP coast would be the worst affected zone with as much as 1706 km² area including about 894 km² under various types of agricultural activities lying within 2.1 m elevation.

1. INTRODUCTION

The levels of carbon dioxide and climate change are interlinked during most of Earth's history (Ahn and Brook, 2009; Goodwin et al., 2009). The present global carbon dioxide levels are a 38% higher than the levels that hovered around 280 ppm during last 2.1 million years (Horisch et al., 2009). Human activities of modern era such as deforestation, fossil fuel burning, draining of wetlands, adoption of modern technology in farming and livestock rearing, etc., are the main reasons for the present degraded state of the global environment. Initially, the impact of such activities on the climate and environment were invisible and insignificant. But with the increasing urbanization and industrialization, the impacts began to show on the world climate patterns and reached such a level at present that it is no more a tomorrow's crisis but very much a today's growing catastrophe (Alexander and Nasheed, 2009). At present (October 2009) the atmospheric carbon dioxide levels are 384.38 ppm (<http://co2now.org/>), an increase of more than 100 ppm from its pre-industrial levels of 260-270 ppm (Wigley, 1983).

Atmospheric warming leads to increased evaporation of ocean water and the resultant increase of water vapour in the atmosphere

would trap more heat setting in a cascading effect. The consequences of global warming both in physical and biological world, by and large, reflect the impact of greenhouse gases (Rosenzweig et al., 2008; Zwiers and Hegerl, 2008). The ramifications of the increased greenhouse gases like carbon dioxide in the atmosphere are already visible. The top 11 warmest years in the recorded history have occurred in the last 13 years (Finerin, 2009). Warming of Earth to such a level would lead to severe consequences such as increasing frequency of weather conditions like droughts, floods and heat waves.

India, like many other countries, has already started bearing the brunt of the extreme weather conditions. For instance, the severe drought that crippled many parts of India in 2002 (Mall et al., 2007), unprecedented floods of 2005 in Mumbai city (Dixon et al., 2008) and droughts in other parts of India the same year (Bhanumurthy and Behara, 2008), and floods in 2008 such as in Kosi River basin indicate the impact of global warming. This year (2009) has proved to be much worse in many parts of India, especially in the southern state of Andhra Pradesh. The deficit in rainfall during 2009 summer monsoon across India is 23% which is

comparable to the most severe droughts of 1972 and 2002 in the last 100 years (Francis and Gadgil, 2009). Ironically, the IPCC (2007) predictions (as quoted by Khullar, 2009) that 'more extreme droughts, floods, and storms, would become commonplace in the future, and that these intense weather conditions would follow in close succession to each other, often in the same areas', appears to become a reality if this year's (2009) experience in the state Andhra Pradesh is considered. The state was subjected to a severe drought due to the failure of summer monsoon which impaired the agricultural operations in the state like elsewhere in the country. The kharif crop failed in 971 out of the total 1128 revenue mandals in the state. The crop failure was total in about 1.35 million hectares while in another 3.4 million hectares the loss was at 50%. As the people and the state government were still grappling with such a severe drought, a low-pressure system that hovered over the Krishna River basin for three days in October 2009 had wreck havoc with unprecedented floods affecting five million people and destroying whatever crop was standing in several parts of Andhra Pradesh within the Krishna River basin. Interestingly, Kurnool district which was one among the worst hit by drought was also severely affected by the floods including marooning of the Kurnool city.

This kind of increasing severity of the weather phenomena, needless to mention, pulls down the agricultural production and topples the economy, especially in agrarian countries like India. Perhaps, the steep increase in food prices that are currently witnessed all over the world is probably the first genuinely global effects of greenhouse gas warming, as the demand for supplies is aggravated by the drought in food-producing regions (Parry et al., 2008).

Apart from this, global warming looks like leading to another major disaster along the coastal zones which are by far the most densely populated regions of the world. Global warming leads to eustatic rise in sea level (Allen and Komar, 2006) due to thermal expansion of seawater and addition of ice-melt water (Meehl et al., 2005). Already there are evidences of large-scale ice melt in the three major ice repositories of the world. The Greenland ice is melting at a rate of $239 \pm 23 \text{ km}^3$ per year (Chen et al., 2006). The extent of Arctic sea ice has been decreasing at almost 8% per decade since the middle of last century (Stroeve et al., 2007). Perhaps the most alarming is the widespread loss of ice in West Antarctica (Rignot et al., 2008) contributing to global sea-level rise of $\sim 0.36 \text{ mm/year}$ (Chen et al., 2008). On the whole, the climate change-induced rise in global sea level is estimated to be 1 - 3 mm/year (Pielke et al., 2008). IPCC (2007) predicted that the global sea level will rise at most 59 cm by 2100. However, many feel that there are inconsistencies in the IPCC estimates (Pielke, 2008; Pielke et al., 2008; Schiermeier, 2008). More recent estimates predict even 1.0 m to 1.5 m rise in sea levels by the end of this century (Stroecker, 2008; Milne et al., 2009). The direct impact of the sea-level rise is on the coastal zones which, in spite of being highly resourceful and densely populated, are low-lying and hence would be subjected to accelerated erosion and shoreline retreat due to increased wave strength as water depth increases near the shore (Pirazzoli, 1996; Pye and Blott, 2006), besides leading to saltwater intrusion into coastal groundwater aquifers, inundation of wetlands and estuaries, and threatening historic and cultural resources as well as infrastructure (Pendleton et al., 2004). The increased sea-surface temperature would also result in frequent and

intensified cyclonic activity and associated storm surges affecting the coastal zones (Unnikrishnan et al., 2006). Probably, the occurrence of major cyclonic storms with unprecedented intensity such as the Super Cyclone that hit Orissa coast in India in 1999; Katrina that hit Louisiana state, USA in 2005; Gonu that hit Oman in 2007; Sidr that hit Bangladesh in 2007 and Nargis that hit Myanmar in 2008 reflect the effects of climate change.

There are indications that sea levels are increasing along the east coast of India too. Studies based on the analysis of long-term tide-gauge data from various stations along the Indian coastal regions, corrections for vertical land movements included, indicated that sea levels are rising at a rate of about 1.0 - 1.75 mm per year due to global warming (Unnikrishnan et al., 2006; Unnikrishnan and Shankar, 2007). Pronounced erosion even along certain major depocentres like deltas of the east coast of India although was mainly attributed to anthropogenic forcing (e.g. Baskaran, 2004; Hema Malini and Nageswara Rao, 2004; Nageswara Rao et al., 2008), perhaps reflect the impact of eustatic sea-level rise as well. In this background it is necessary to identify the vulnerable sections of the coast and assess the possible loss of land and property to future sea-level rise. This study, therefore, is an attempt to map the vulnerable sections and to estimate the possible loss to the agricultural activities along various coastal sectors of Andhra Pradesh state using the remote sensing and GIS techniques.

2. STUDY AREA

The present study area is the 1030-km-long coast of Andhra Pradesh (AP) State including the 300-km-long Krishna-Godavari delta front with a very wide coastal zone dominating its central part (Fig. 1). The coastal sector north of these deltas is characterized by headland-bay configuration with a number of rock promontories jutting into the sea, especially over a 185 km stretch on both sides of Visakhapatnam city. Therefore, the width of the coastal zone is very narrow in this part. The southern side of the Krishna-Godavari delta region, however, is again wider with the presence of the Penner River delta and Pulicat Lake. In this study, 5-m contour is taken arbitrarily as the landward limit of the coast. The region is densely populated with more than 6.5 million people (2001 census) living within 5-m-elevation above the sea level including the port cities of Visakhapatnam, Kakinada and Machilipatnam. The AP coast is known for frequent tropical cyclones and associated floods and tidal surges causing loss of standing crops, life and property in the region. For example, the 1977 cyclone that was accompanied by a 5-m storm surge killed about 10,000 people and 0.2 million livestock besides causing enormous damage to standing crops and property in the Krishna delta region. The 3 to 4 meter storm surges in the 1990 and 1996 killed thousands of people and livestock, besides damaging agricultural lands and property in Godavari delta region.

3. METHODS OF STUDY

The land use / land cover features along the entire Andhra Pradesh coast have been interpreted from the IRS P6 LISS III images from 2008. Initially, all the raw data products were geocoded and seamlessly assembled to form a single contiguous image of the entire coast. The image was then subset by taking the landward limit of the coast up to 5-m contour. In order to generate the 5-m contour, digital elevation models (DEM) of the AP coastal area

available on the internet from the Shuttle Radar Topographic Mission (SRTM) website (www.srtm.csi-cgiar.org) were downloaded from which contours at required interval are interpolated using the 3-D Analyst module in ArcGIS software. All the land use /land cover features within the 5-m elevation along the coastal zone of AP were traced through onscreen digitization and the area statistics for all the features were extracted. Later, the contour lines representing 1.5 m and 2.1 elevations were overlaid on the land use/land cover map and the data on various land use features and their areal extents were extracted within 1.5 m and 2.1 m elevations, respectively. The number of villages lying within 2.1 m elevation was also extracted by overlaying the 2.1 m contour line on the geocoded village boundary layer, and the data on population within these villages were obtained from the 2001 Census records. The land use / land cover map of the entire Andhra Pradesh coast is further subset to separate out the Krishna-Godavari delta region where the impact of the sea-level rise would be more significant than any in other part of the region. The area statistics on the various features within 1.5 m, 2.1 m and 5.0m contours in these deltas are also extracted from the GIS analysis.

4. LAND USE / LAND COVER

The area covered within 5 m elevation along the 1030-km-long coastal zone of Andhra Pradesh is about 10,026 km². The area is essentially an agricultural region. The land use/land cover map prepared based on the interpretation of IRS P6 LISS III images showed broad classes of various cultural as well as natural features in the region (Fig. 1). About 5027 km² (50.14%) of the area is under seasonal crops of which paddy is the dominant crop. Aquaculture has become another major primary economic activity in the region spread over 1692 km² (16.88%). Plantations such as coconut, mango, guava, banana and cashew, besides casuarina occupy about 1496 km² (14.92%), especially in the lower reaches of the Godavari delta and on the sandy beach ridge zone all along the coastal zone of the state. Salt pans are the other cultural feature that covers about 232 km² (2.31%). Apart from these cultural features, coastal wetlands such as mangrove swamps, lagoons, mudflats, tidal creeks, etc., occupy as much as 1579 km² (15.75%) area, especially fringing the coastline.

Most part of the Andhra Pradesh coastal zone under study comes within the Krishna and Godavari delta region. Out of the total area of 10,026 km², these twin deltas alone account for about 7045 km² (70.27%) of the area. Owing to the extremely gentle nature of the slope in these deltas, the 5 m contour lies almost 30 km inland here, while in the remaining coastal part of the state it runs within 5 – 10 km inland from the shoreline. Of all the land use / land cover features in the Krishna-Godavari delta region, paddy is the dominant crop occupying about 4606 km² (65.38%). Rich alluvial soils and water resources (through dense network of irrigation canals as well as plentiful groundwater) of the Krishna-Godavari delta region sustain intensive paddy cultivation in both Kharif and Rabi seasons. Therefore almost 91.63% of the paddy area within 5 m elevation along the AP coast is in the Krishna-Godavari deltas alone (Fig.2). It may be noted that the Krishna-Godavari twin delta region is known as the rice-bowl of Andhra Pradesh. Apart from paddy, aquaculture is also prominent in the twin delta region. Out of the total 1692 km² area under aquaculture along the entire coast, as much as 1427 km² (84.34 %) is within these deltas. The extensive mudflats and tidal creeks made the area conducive for the development of prawn culture. Besides, the entrepreneurial farmers

in the region have converted some of their cropland into aquaponds for fish culture in a big way utilizing the available freshwater resources (irrigation canals/groundwater). Plantations such as coconut, mango, guava and banana are commonly found in some parts of these deltas. Casuarina occupies mostly the sand dunes and beach ridges acting as windbreaker and sand stabilizer in this cyclone-prone area. Altogether, plantations occupy an area of about 322 km² (4.57%) in the delta region. Salt pans also cover about 78 km² area in the lower reaches of the deltas. Another characteristic feature of the Krishna-Godavari delta region is the presence of extensive mangrove swamp and associated mudflats and lagoons. Occupying about 612 km² area, the wetlands of this region is second only to Sundarbans in India. The mangrove swamps are an important coastal wetland ecosystem protecting the coastal land from erosion and impact of storm surges. On many an occasion in the past, mangrove forest in this region is said to have saved life and property from the fury of the gale winds and occasional surges that are associate with the cyclones storms that frequent this part of the AP coast.

5. RESULTS AND DISCUSSION

The contour lines representing the 0.6 m, 1.5 m, and 2.1 m elevations extracted from the SRTM data are overlaid on the land use/land cover map in order to understand the impact of predicted sea-level rise along the AP coast. Initially, the land use/land cover features within the present intertidal zone and the future intertidal zone are computed to gauge the effect of sea-level rise. If the sea level rises by 0.6 m by 2100 AD as predicted by IPCC (2007), the area between the present shoreline and 0.6 m elevation would be submerged. The existing land use/land cover features and their areal extents are estimated. Similarly, the area between the present high-tide line (1.5 m) and the future high tide line is demarcated and the land use/land cover futures within this zone are evaluated.

5.1 Present Intertidal Zone

The AP coast is under the influence of a micro-tidal environment. The tidal range along the entire coast is from 0.7 m as at Krishnapatnam in the south to 1.5 m recorded at Visakhapatnam in the northern sections. Considering the seasonal fluctuations and storm tide conditions, the average spring high-tide limit of 1.5 m is taken in this study, and as such the inter-tidal zone is demarcated within the 1.5 m elevation from the shoreline. As detailed in the methods of study, the contours representing the 1.5 m, 2.1 m and 5.0 m elevations along the AP coast are generated from the analysis of SRTM data. It may be noted that the 1.5 m line could not be shown in Figure 1 due to scale limitations. However, it is clearly visible in Figure 2 because the 1.5 m contour is at considerable distance from the shoreline in the gently sloping Krishna-Godavari delta region.

When the 1.5-m-contour is superimposed over the land use/land cover map, it almost coincides with the landward limit of the coastal wetland ecosystems like mangrove swamps (Fig.3a), mudflats (Fig.3b), lagoons and tidal creeks. However, human activities in the form of salt pans (Fig.3c) and especially aquaculture (Fig.3d) have encroached into the inter-tidal zone occupying about 96 km² and 232 km² respectively along the AP coast. On the whole, the present inter-tidal zone between the shoreline and 1.5 m contour, covers an area of about 1906 km² of which 812 km² (42.60 %) is within the Krishna-Godavari delta region alone.

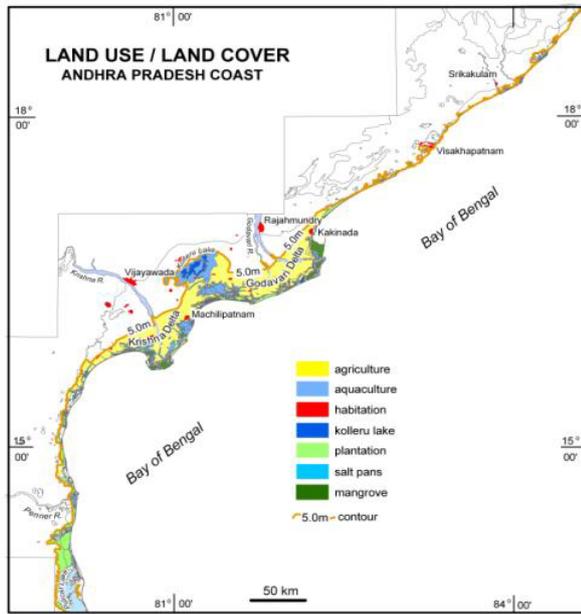


Figure 1. Land use/land cover features within 5.0 m elevation along the AP coast traced from IRS P6 LISS III images of different paths/rows and different dates in 2008

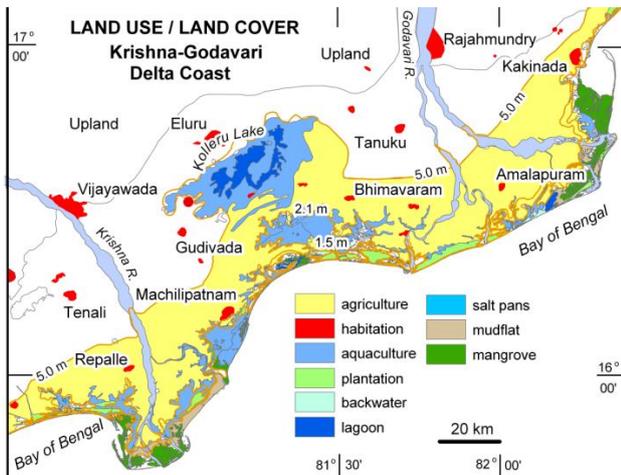


Figure 2. Land use/land cover features within 5.0 m elevation in the Krishna-Godavari delta region, in the central part of the AP coast. Note the 1.5 m, 2.1 m and 5.0 m contour lines traced from IRS P6 LISS III of Path 102/Row 061, dated 3 March 2008 and Path 103/Row 61, dated 8 March 2008



Figure 3. Photographs showing the various land use/land cover features in the Krishna-Godavari delta region.

5.2 Future Inter-Tidal Zone

Considering the IPCC (2007) estimates that the global sea-levels may rise by about 0.59 m by 2100 AD (notwithstanding the more recent estimates on possible sea-level rise of about 1.0 m to 1.5 m), an assessment is made in this study to compute its possible impact along AP coast. If the sea levels rise by ~0.60 m above the present, an area of about 565 km² lying in between the present shoreline and the 0.6 m elevation would go below the low tide including the 150 km² area along the Krishna-Godavari delta front coast (Nageswara Rao et al., 2008). Further, the high tide line would shift landward from the present 1.5 m contour to 2.1 m contour. Therefore, the present area lying between 1.5 m and 2.1 m contours would become a part of the future inter-tidal zone. At present, this area is occupied by aquaculture over 499 km², agriculture over 319 km² plantations over 279 km² while salt pans occupying about 136 km². Thus the entire 1233 km² area along the AP coast would be affected by the regular tides in future, if the sea-levels rise by 0.60 m. Out of this 1233 km² area which would join the future inter-tidal zone, as much as 894 km² is within the Krishna-Godavari deltas alone, including 474 km² under aquaculture, 311 km² under agriculture (Fig.3e), 80 km² under plantations (Fig.3f) and 29 km² under salt pans.

There are many villages located close to the present high tide limit. An analysis of the village location map in comparison with the contour map showed that as many as 282 revenue villages are located within 2.1 m elevation along the AP coast. All these villages and 1.29 million people living there would be in danger if the sea level rises by 0.6 m above its present level. Within the Krishna-Godavari delta region the increased sea levels would affect 97 human habitations and 0.57 million people.

Apart from these direct impacts, the sea-level rise might also affect the region indirectly through landward shift of freshwater-seawater interface and consequent groundwater contamination by salinization. Earlier studies indicated that the groundwater quality in the Godavari delta is already affected due to considerable advance in the seawater intrusion (Ghosh, 2002). The situation in the Krishna delta is much worse as widespread seawater intrusion is transforming the fresh groundwater to brackish/saline water (Saxena *et al.*, 2004), even up to 50 km inland (Mondal *et al.*, 2008, 2009), which is evident from the presence of trace elements like strontium and boron in the groundwater here (Saxena *et al.*, 2004; Mondal *et al.*, 2009).

CONCLUSION

The study revealed that the impending sea-level rise would seriously impair the agricultural activities in the lower parts of the AP coastal zone, especially in the low-lying Krishna-Godavari twin delta region which is considered as the rice-bowl of the state. The land use / land cover map prepared using IRS P6 LISS III images from 2008, coupled with elevation data generated from SRTM DEMs indicated that agriculture, with paddy as the dominant crop, is the major land use activity in the zone under study followed by aquaculture. If the sea level rises by 0.6 m as predicted by IPCC (2007), an area of about 532 km² including 150 km² in the Krishna-Godavari deltas at present lying between the shoreline and the 0.6 m elevation would be permanently submerged under the future low-tide level. Further an area of about 1233 km² including 894 km² Area within the Krishna-Godavari deltas lying between the present high tide line (1.5 m) and the future high-tide line (2.1 m) would go under the future inter-tidal zone, affecting the cropland over 319 km², aquaculture over 499 km² and plantations over 279 km², besides threatening the survival of 1.29 million people living in 282 coastal villages along the entire AP coast.

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