CHAPTER - 5

IMPACT OF POSSIBLE SEA LEVEL RISE :
A CASE STUDY OF PARADIP COAST, ORISSA

Introduction :

For over a century scientists have known that the carbon dioxide and water vapour in the atmosphere warm our planet by absorbing outgoing infrared radiation. This feature of the climate is commonly known as the "Green House Effect". Gases that absorb infrared radiation are known as green house gases. Without this effect earth would be much colder than it is today.

Among the immediate concerns regarding the environmental effects that may result from this change in climate, is a rise in sea level. Impact of sea level rise will be more severe than a corresponding global warming of atmosphere; as due to CO₂ induced climate change we are not going to be fried rather we will be drowned.

Since the realisation of irreversible effects of sea level rise, research in this field has gained considerable momentum in the last decade particularly in western countries. At the same time the research trend seem to be shifting from causes towards the impacts direction.

Area of Case Study :

The area chosen for the study of impacts of possible sea level rise is Paradeep and its adjoining areas located
in Cuttack district of Orissa. The area forms a part of the low coastal plain along the East coast of India situated in the Mahanadi delta surrounding the mouth of the river.

**Objective:**

Attempt has been made in this work to study the geomorphic impacts and effects on population and land use of the area due to future rise in sea level. In the geomorphic studies the influence of local factors and processes which may be operating actively have not been taken into account, those are magnitude of sediment discharge from rivers to the sea, local tectonic activities, subsidence of nearshore bottom due to increased water load, atmospheric parameters etc. Also for the population and land use studies the current data only has been examined. It does not take into account the future measures, adaptive responses or future changes in the distribution of population and land use. Hence the result is a rough approximation of the future stakes. The area is a low coastal plain made up of alluvial sediments. In the geomorphic study, the total area to be submerged due to sea level rise and the resulting effects have been discussed. Then the erosion potential of the beaches has been determined. Following this, the impacts on population and land use have been discussed. Throughout this study all the figures and discussions given are for the future impacts only.
Importance of the Study:

The present topic has been chosen keeping in view the disastrous consequences of future rise in sea level. Because of its immediate impacts on many aspects of human life, it necessitates the involvement of scientists and scholars in this study. And also this type of work helps in one or other way in coastal planning and management by the government and other agencies working for the betterment of coastal communities.

Secondly, slope is the chief controlling factor with regard to horizontal shoreline displacement. Along the East coast of India slopes are gentler and areal extensions of deltas are more compared to those of West coast. So the severity of the effects due to sea level rise will be more in the East Coast.

Study Approach:

In the present study two types of study have been undertaken: geomorphic impacts and the effects on population and land use. Two scales of future scenarios of sea level rise have been used in this case study. The first one is: to show the area of submergence and the effects on population and land use for which two scenarios were examined. The more optimistic scenarios assumes a future 1 meter rise in sea level. The more pessimistic high figure assumes a 3 meter rise in sea level.
Then coming to show erosion potential another scale has been adopted, i.e. the world-wide rate of eustatic sea level rise (1.2 mm/yr.).

**Preparation of Flood Map:**

Paradeep and its adjoining areas have been taken as the area of focus. The final map of this area was prepared with the help of maps given in the Census Handbook. The flood map (showing area of submergence and relief) was procured from Deptt. of Geography, Utkal University. In that map heights of the contours are given in feet. Those were converted to metres and the one and three meter lines were drawn which are taken as the future shorelines as the sea level rise by 1 meter and 3 meter respectively. The new shorelines were drawn from the present high water line. Hence the 1 meter and 3 meter lines represent the limit of highwater rather than the mean sea level.

**Estimation of the Area of Submergence:**

The areas that are going to be submerged when the new shorelines of one meter and three meter were projected on the study area, were estimated by planimeter.

**Application of Bruun Theory:**

The Bruun rule of shore erosion has been applied to estimate the erosion potential of this area due to sea level rise. According to Bruun rule as the sea level rises material eroded from the upper beach is deposited on the nearshore bottom. As the sea level rises by "a" unit the
The quantity of material needed to reestablish the same bottom depth over a width of shelf "b" is "b" times "a" (i.e. ba). The quantity "ba" is derived from the shore erosion. This will give rise to a shore recession of "x". If the elevation of the shore is "e" the quantity eroded above the shore is "xe". Meanwhile, to reestablish the original bottom profile, the entire profile must be moved shoreward by the same distance "x" up to a depth "d" at distance "b" from the shoreline. The balance between eroded and deposited quantities is expressed by \( x(e+d) + ab \) or the magnitude of shore recession

\[
x = \frac{ab}{e+d}
\]

To apply this rule, the three variables, "b", "d" and "e" ("a" is the rate of sea level rise) are to obtained from the beach profile.

Beach profiles at four locations were procured from Paradeep Port Trust Authority. With these beach profiles future erosion potentials were calculated applying Bruun rule.

**Effects on Population and Land Use of the Area:**

The effect on population and the land use of the area have been examined village wise. The map showing distribution of villages in the study areas was prepared with the help of Census Handbook. Then the earlier prepared flood map (showing one meter and three meter shorelines) was
superimposed on the village map.

The population and land use of the villages were estimated that are to be submerged due to one meter and three meter rises in sea level. The village wise population and land use data were obtained from the same Census Handbook.

Geographical Setting:

Location: For the present work studies were undertaken for Paradeep town and its adjoining areas. The area lying between 20° 1' and 20° 31' N and 86°15'E and 86°46'E constitutes most of the coastal tract of Cuttack district. It also forms a significant part of the Mahanadi-Kathojori delta system located along the Bay of Bengal, the area consists of four P.S. areas. Paradeep is located at the mouth of the Mahanadi river and of four police stations areas Ersama and Tirtol lie south of Mahanadi river and Patkura and Mahakalpara to the north. All these five areas (Maakalpara, Patkura, Ersama, Tirtol and Paradeep) taken here as the sub-areas of the whole study area. Paradeep is 120 km away from Bhubneshwar, the state capital.

Climate: The climate of the area is humid and tropical in nature. There are three distinct seasons in the area, the winter season from November to February is followed by summer from March to mid-June and the third from mid-June to October is the monsoon period. During the last mentioned
LOCATION OF THE AREA IN THE INDIA MAP

LOCATION OF THE STUDY AREA (DARKENED) IN THE INDIA MAP
LOCATION OF THE AREA IN THE DISTRICT MAP

scale

LOCATION OF THE STUDY AREA (SHAPED) IN THE DISTRICT MAP.

SOURCE: DISTRICT CENSUS HANDBOOK, CUTTACK DISTRICT.
MAP OF THE STUDY AREA.

SOURCE: DISTRICT CENSUS HANDBOOK, CUTTACK DISTRICT.

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period the area experiences heavy rainfall by south-west monsoon. The spring autumn and dewy seasons are actually of very short duration and also are least felt.

The average annual rainfall is about 1572 mm falling mostly during SW monsoon from June to Sept (73%) and during NE monsoon from October to December (17%). Uncertainty in the distribution of rainfall prevails even in the monsoon months. Inundations due to occasional high floods keep many areas water-logged and swampy besides bringing damage to life and property.

Temperature and humidity are high throughout the year. The mean maximum monthly temperature ranges from $29^\circ\text{C}$ to $43.4^\circ\text{C}$ and mean minimum temperature from $12^\circ\text{C}$ to $24^\circ\text{C}$. The mean monthly humidity ranges from 41 per cent to 86 per cent.

The mean monthly wind speed varies from 2.6 kmph to 26.2 kmph. However, the area is sometimes subjected to severe cyclonic storms which arise out of depressions formed in the Bay of Bengal. Here the wind speed may rise upto 200 kmph particularly in the coastal belt. This is sometimes accompanied by tidal bores of 6 m to 7 m high and very heavy rainfall in the affected areas.

Special weather phenomenon like hail storm, dust storm, fog, thunder storm etc. occur at times and are sporadic in nature. But the area is not prone to any of such weather vagaries.
RELIEF MAP OF THE AREA
(Figures given are contours in feet)

Scale

Paradeep

BAY OF BENGAI

RELIEF MAP OF THE AREA CONTOUR heights are given in feet.
SOURCE: DEPARTMENT OF GEOGRAPHY, Utkal University.
**Topography**: The flatness of the area is due to its deltaic nature. The highest lands are located generally along the river branches which dissect the delta, forming doabs (area between two rivers). The doabs tend to slope down from the top of the delta apex to the bottom at the coast. The slopes in the doabs are generally in the range of 1:500. The land form is quite flat but broken by numerous small and large natural drainage lines, minor depressions and slightly elevated areas. Small streams and creak in the doab interior flow into the larger streams and provide the primary natural drainage for the doab.

**Geomorphology**: The geomorphology of the area comprises of varied regional and local landforms and belongs to different ages and modes of origin. The western part of the area which more or less belongs to the Mahanadi delta head is controlled by weathering, erosion and mass-wasting processes. In the fluvial plains sediments are deposited in fluvial environments by rivers and along the west both fluvial and marine processes operate together. Wind has been an important co-agent working with both fluvial and marine agents to give rise to many geomorphic features like river channels dunes, beach dunes, beach sand dunes etc.

The distributory system has formed at lower reaches of the delta and ultimately meets the sea at several discharge points. Both fluvial and marine forces operate to distribute the river-borne sediments, the result has been the growth of
OMORPHOLOGY OF THE STUDY AREA

REFERENCE

- Inselbergs
- Present rivers/channels
- Ancient beach ridges
- Coastal sand dunes
- Mud flats
- Swamps/marshes
- Ancient channels
- Middle delta plain
- Most plain

MAP SHOWING GEOMORPHOLOGY OF THE STUDY AREA.

SOURCE: S.K. Mahakik, IN J.E. UNIVERSITY
a vast deltaic plain partly fluvial, partly marine and partly mixed.

The ill-drained areas (swamps) lie in the centre of all doabs and constitute important geomorphic features in the alluvial flood plains. They are the lowest areas in between the present day active distributaries and there is difficulty in natural drainage of these areas.

**Drainage**: Different from early mentioned channels, another class of channels are also observed in the area, which carry water that accumulate in the flood plain either due to rain or excess spill from the active distributaries during floods. They occupy the lowest contours of the doabs and carry very little sediment. They are termed as drainage chanells. Some important channels are:

i) The drainage channel Gobri is observed along the Birupa-Brahmni-Nuna doab.

ii) Hansada-Bodnala-Saulia drainage channel draining at Jatadharmuhan to the sea.

The drainage pattern in the Mahanadi delta is radial and parallel. Most of the rivers take significant turns close to the sea. The main rivers Mahanadi and Devi turn at right angles in a anticlockwise direction and run parallel to the west before meeting the sea. All the drainages in the Mahanadi Devi doab run parallel to the west in a SW-NE directions. The Jatadharmuhan is an example of such drainage parallel to the coast. The bends in Mahanadi and Devi might
DRAINAGE MAP OF THE STUDY AREA.

SOURCE: DEPARTMENT OF GEOGRAPHY, UTKAL UNIVERSITY
be due to effects of longshore currents and presence of ancient beach ridges.

**Soils**: The soils in the area are mostly river transported alluvial soils which are moderately sandy along the rivers to sandy clay loam in the low lying areas. In general, the soil becomes heavier and deeper from river edges to the doab interiors and delta close to the sea. In the lower areas the soils are moist and pole yellow in colour. They are moderately fertile and slightly acidic.

**Vegetation**: A very small percentage of this area is under forest. Most of the flat low lying areas are devoted to agriculture. Natural vegetation is in the form of littoral forests, marshes and swamps scrub woodland etc. Tropical wet deciduous forests in a haphazard manner are found here. Littoral forests occur in a narrow strip along the sea coast.

**Agriculture**: Paddy is the primary crop of this area covering nearly all the irrigated area in the Kharif season and some 28 per cent area in the Rabi season. Although the soil is ideal for paddy cultivation, potential for high productivity depends primarily on elevation (which have less flooding and water logging damage) and intensity and duration of inundation during each season. There are also considerable areas of relatively light soils, well-suited for diversified cultivation, but productivity here also tends to be limited by poor-drainage condition.
The paddy yield in the delta is very low, which for irrigated rice is among the lowest in India. Prior to the construction of Hira Kund dam in the early 1960s, the yield was still lower.

State of Knowledge:

Literatures on sea level change has grown exponentially in the last twenty-five years.

Effects of Climatic Change: As a result of increasing rate of modernisation and industrialisation, atmospheric concentration of CO₂ etc. are increasing at an alarming rate while due to wide-scale deforestation mostly in the developing countries absorption of rate of CO₂ has come down substantially.

The combined effect is an increasing rate of concentration of CO₂, CH₄, CFC, NO₂ etc.; the impact of which is many faceted. The areas which need immediate attention as the impact is going to be severe are green house effect, ecological impact, effects in agriculture and forestry and sea level rise.

Recent measurements show that the concentration of CO₂, CH₄, CFC, NO₂ and other gases released by human activities are increasing at an alarming rate. Because these gases can trap infrared (heat) part of the insolation, scientists expect the earth to warm substantially. Although some scientists have indicated some under-defined factors which may help reduce warming rate. The National Academy of
Science, USA has ruled out all such possibilities. The trapping of solar heat by the atmosphere in a manner somewhat analogous to the glass panels of a green house, is known as greenhouse effect. Without the greenhouse effect the earth would be approximately $33^\circ C$ colder than it is today.\footnote{1}

Although people may adapt to climatic changes upto a considerable period, other species which are going to be affected may not be able to control their habitats. The changes in climate would place multiple stresses on some species which would become extinct resulting in a significant decline in biodiversity. The warming could also affect agriculture and forestry by altering water availability, length of growing season and the number of extreme days.

The most disastrous consequence of a global warming would be a rise in sea level. A few degree warming could be expected to raise the sea level in the future as it has done in the past.\footnote{2}

*Causes of Sea Level Change*: Global warming results in sea level rise in two ways, by thermal expansion of ocean water and deglaciation of the ice masses.

Apart from global warming, other less significant factors also need to be mentioned. These factors influence the sea level mostly in local and regional scale. One of such factors is terrain subsidence due to crustal downthrust.
and/or sediment compaction. The work of Newman et.al.\(^3\) suggests that the value of sea level increase can simply be correlated with a typical subsidence rate. Paulmbo and Mazzarella\(^4\) have classified some other factors as external and internal sources of sea level rise. These factors mostly effect short term variations in sea level. These sources include atmospheric pressure, rainfall, evaporation rate, surface water density etc.

**Records of Past Rises**: Sea level has risen and fallen by over 300 meter throughout the geologic history. It has been established that during the last age (15,000 years ago) mean sea level was approximately 100 m lower than the present level when the global temperature was 50\(^{\circ}\)C colder than the present temperature.\(^5\) Sea level rise was most rapid upto 6000 years ago after which the rate became quite slow.

The last century has witnessed that mean sea level has maintained a steady rise on a global scale, much in consonant with the steady rise in the concentration of atmospheric green-house gases. Combined studies have concluded that the average world-wide sea level has risen 10-15 cm in the last century.\(^6\) This has been attributed to ocean water expansion and meltwater from mountain glaciers.

**Future Estimates**: Groups of workers have attempted to project the future rises in sea level which have some direct relationship with the global warming.
Global Temperatures and Sea level rise in the last century.

Bruun\textsuperscript{7} has given an early estimates that the complete deglaciation of the existing ice mass (of approximately 37.5 x 10\textsuperscript{6} cu cm) would cause a sea level rise of 95 meter. But due to oceanic crustal lowering and to the fact that the rising sea would spill over a enormous coastal lowlands, the final level of the ocean might be perhaps only approximately 50 meter above the present level.

According to Revelle\textsuperscript{8} on the basis of a global warming of 3-4\textdegree C in the next century thermal expansion of ocean water would result a 30-50 cm rise in sea level and deglaciation of Greenland and mountain glaciers would contribute 10-30 cm each (assumed that no Antarctica deglaciation would take place in this period).

Hoffman et.al.\textsuperscript{9} estimated that sea level was likely to rise between 26 and 39 cm by the year 2025 and between 91 and 137 cm by 2075. Later in 1986 they revised their projection and estimated the rise by 2025 to be between 10 and 21 cm and by 2075 to be between 36 and 91 cm. According to Thomas, the total sea level rise by 2100 is estimated to be 0.9 to 1.7 meter with a preferred value close to 110 cm.\textsuperscript{10}

Although the impact of Antarctica is unknown it is generally agreed that a complete deglaciation of west Antarctica ice sheet would result a 5-7 cm rise in sea level which could take 3 to 5 centuries. Thomas estimated that the Antarctica contribution resulting from a 4\textdegree C warming would most likely to be 28 cm, but could be as high as 2.2 meter.
Contribution to Future Sea Level Rise in the Year 2100 [in centimeters]

<table>
<thead>
<tr>
<th>Study</th>
<th>Thermal Expansion</th>
<th>Alpine Glaciers</th>
<th>Greenland</th>
<th>Antarctica</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoffman et al. (1986)</td>
<td>28-83</td>
<td>12-37</td>
<td>6-27</td>
<td>12-220</td>
<td>57-366</td>
</tr>
<tr>
<td>Thomas (1985)</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>0-229</td>
<td>--</td>
</tr>
<tr>
<td>Meier (1984)</td>
<td>--</td>
<td>10-30</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Hoffman et al. (1983)</td>
<td>28-115</td>
<td>b</td>
<td>b</td>
<td>b</td>
<td>56-345</td>
</tr>
<tr>
<td>Revelle (1985)</td>
<td>30</td>
<td>12</td>
<td>12</td>
<td>c</td>
<td>70</td>
</tr>
</tbody>
</table>

a Contribution in the year 2085.
b Hoffman et al. assumed that the glacial contribution would be one to two times the contribution of thermal expansion.
c Revelle attributes 16 cm to other factors.

TABLE 3.2

Temporal Estimates of Future Sea Level Rise [in centimeters]

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2000</td>
</tr>
<tr>
<td>------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>Hoffman et al. (1986)</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>5.5</td>
</tr>
<tr>
<td>Hoffman et al. (1983)</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>8.8</td>
</tr>
<tr>
<td></td>
<td>13.2</td>
</tr>
<tr>
<td>Revelle (1983)</td>
<td>--</td>
</tr>
</tbody>
</table>

a Other studies only provided an estimate for a specific year.
Total Sea Level Rise During the Next Century

The dark shading indicates the most probable response to the climate scenario. The broken line depicts the response to a warming trend delayed 100 years by thermal inertia of the ocean. A global warming of 6°C by 2100, which represents an extreme upper limit, would result in a sea level rise of about 2.3 m, but errors on this estimate are very large.

**General Effects of Sea-Level Rise**: A sea level rise tends to cause a general recession of the shoreline due to inundation and/or erosion except where this trend is totally off-set by an adequate influx of sediment. Inundation is the submergence of the unaltered shore, while erosion is the physical removal of the shore material.

By submergence uplands are slowly converted to marsh lands. For this Kanna et. al.\textsuperscript{11} have given drowned valley concept. Here slope is the chief controlling variable. Steep slope areas will experience little horizontal shoreline displacement with each increment of water level rise, while gently slopping shores will undergo a much broader area of flooding for a given sea level rise.

The relationship between the rising sea level and beach was first formulated by Bruun.\textsuperscript{12} This is known as Bruun theory, which holds that assuming a profile of equilibrium, as the sea level rises, material eroded from the upper beach is deposited on the nearshore bottom. Quantitative relationship in this exchange are as follows:

a) There is a shoreward displacement of the beach profile as the upper beach is eroded.

b) The material eroded from the upper beach is equal in volume to the material deposited on the nearshore bottom.

c) The rise of the nearshore bottom as a result of this deposition is equal to the rise in sea level, thus maintaining a constant water depth in that area.
Fig. 3.3 - Drowned valley concept

Thus it is a two-dimensional quantitative relationship. Bruun applied his rule in Florida coast and Gulf coast (Santa Rosa Island) to test the validity.

After the publication of this theory, several workers have performed regional tests, most of which have been ended up with fair degree of accuracy. The regional tests which need mention are those of Schwartz\textsuperscript{13} at Cape cod beaches (Massachussats) and Rosen\textsuperscript{14} at Virginia Chespeake Bay etc.

With sea level rise both the processes erosion and submergence may act jointly. Leatherman\textsuperscript{15} has illustrated this combined effect. The term $D_1$ represents the landward movement of the sea due to simple submergence of the land, for which the response time is instantaneous. The second displacement term $D_2$ refers to coastal erosion. Thus $D_1 + D_2$ represents the combined effect due to the sea level rise.

Sea level rise would also result coastal flooding in many ways Titus et.al. observed.\textsuperscript{16} Natural drainage would be decreased because of higher ground water table, decreased hydraulic head on the surface etc. More areas will be flooded by spring tides.

The effects will be more pronounced in the coastal lowlands where the population land-use and economic set-up will get severely affected.
1. Influence of sea-level rise on the development of beach and offshore profile.

SOURCE: Brown (1967)
Area of submergence in 1m and 3m rise in the sea level in the study area.
Impact of Possible Sea-Level Rise on Study Area:

The area forms a part of the coastal plain which slopes gently seaward. Therefore, a slight rise in the sea level could cause a significant horizontal displacement of the shoreline. With a one meter rise of sea level the area of submergence will be 335.67 sq.km. which is 19.9 per cent of the study area and with three meter the figures are 905.52 sq.km. and 53.7 per cent respectively.

Effects on Wetlands: The one meter shoreline will submerge all the wetlands lying around the mouth of Mahanadi river and more than three-fourth of the wetlands present around the Jatadharmuhan river. These lands normally store flood water and provide protection from storm surges and high tides (allowing excess water to spill over there). With the loss of these lands new lands of relatively lower elevation than the surrounding areas may be converted to wetlands. In other words wetland loss would remove an important barrier to storm surges etc. The three meter shoreline will submerge all the remaining wetlands in the area.

Coastal Flooding and River Damming: The sea level rise causes coastal flooding in two ways: storm surge and backwater effect, the effective area to be affected will be more than what is estimated, when storm surges (which takes place in the vicinity of the coast) will cross the future shoreline (1m or 3m).
### Table 5.1. Area of Submergence (in sq. km.)

<table>
<thead>
<tr>
<th>Sub areas</th>
<th>Total Area</th>
<th>for 1 m</th>
<th>for 3 m</th>
<th>Unaffected area</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAHAKALPADA</td>
<td>376.77</td>
<td>151.71</td>
<td>340.1</td>
<td>36.68</td>
</tr>
<tr>
<td>PATKURA</td>
<td>380.26</td>
<td>0</td>
<td>69.14</td>
<td>311.12</td>
</tr>
<tr>
<td>ERSAMA</td>
<td>382.5</td>
<td>145.59</td>
<td>357.35</td>
<td>25.09</td>
</tr>
<tr>
<td>TIRTOL</td>
<td>523.49</td>
<td>19.27</td>
<td>115.62</td>
<td>407.87</td>
</tr>
<tr>
<td>PARADEEP</td>
<td>23.31</td>
<td>19.1</td>
<td>23.31</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1686.33</strong></td>
<td><strong>335.67</strong></td>
<td><strong>905.52</strong></td>
<td><strong>780.76</strong></td>
</tr>
<tr>
<td><strong>PERCENTAGE</strong></td>
<td><strong>100</strong></td>
<td><strong>19.9</strong></td>
<td><strong>53.7</strong></td>
<td><strong>46.3</strong></td>
</tr>
</tbody>
</table>
The floodwater from upstream backs up along the river because of a rise in sea level at the basin outlets. This is known as backwater effect. This will be hard-felt particularly along the major rivers like Mahanadi, Santara etc. in this area. Again the flatness of the area will enhance this problem. The result will be flooding of river water across the levees. This effect will diminish gradually towards upstream direction. The flatness which exists along the upper reaches of the major rivers would bring fear that the future rises of sea level would threaten more areas than portrayed in the present scenerios. These flat areas now frequently experience severe flooding (mostly during the monsoon seasons). If the scenerios, discussed here unfolds, flooding might intensify in these regions.

The sea level rise will also effect damming of the river courses resulting in the reduction in sediment discharge to the sea. Thus the deposition of excess sediments enroute would add to local subsidence due to overloading and sediment compaction.

Effects on Drainage: The area is marked by high drainage density. This surface drainage will again be increased when the rise in sea level would result. Rise in ground-water table which in turn would reduce underground drainage. Increase in the water levels in the rivers and high tides would cause substantial lowering of hydraulic head (the difference in elevation between source to sink) along the
slopes which will further slow down the drainage process.

Decreased flow rates along the channels would allow more siltation and deposition. Thus the effective capacity of the river would decrease. All these would ultimately result a higher drainage density (which will include new channels), slow and poor drainage in the area.

**Shore Retreat Due to Erosion**: The erosion potential of the study area due to sea level rise has been determined applying Bruun rule, at four beach locations.

The locations are:

Beach Profile No. 1 - It is 2.25 km south of Paradeep port along the shore.

Beach Profile No. 2 - It is 1 km north of Paradeep port.

Beach Profile No. 3 - It is 3.75 km north of Paradeep port.

Beach Profile No. 4 - It is 8 km north of Paradeep port.

According to Bruun rule the rate of shore erosion

\[
X = \frac{ab}{e+d}
\]

where

- \(a\) = rate of sea level rise
- \(b\) = width of the shelf
- \(e\) = shore elevation
- \(d\) = depth at distance 'b'

In all the following calculations the rate of sea level rise (the quantity 'a') has been taken as 1.2 mm/year which is the world-wide eustatic sea level rise rate. For the quantity 'd', it is the 18 meter depth; the limiting depth between the nearshore and off-shore material.
For sandy open sea shores Bruun assumed the value of 'd' as 18 meter, the depth contour which forms some kind of limit between nearshore and deep sea littoral drift phenomena. Again the slope of the shelf is of prime importance here. The transverse migration of eroded sediments is retarded by the gentle slope which exists at around 18 meter depth in most of the shores of open and sandy character. With a close look at the beach profiles drawn for the study area, it can be marked that the slope between 12 meter and 18 meter depths (approximately) is gentle enough to retard the transverse movement of the sediments. Hence the depth contour 18 meter has been taken here as the outer limit of nearshore sediment migration. This figure (for quantity 'd') is also approximately same for most other shores world-wide.

Shore retreat at location - 1

\[
\frac{ab}{e+d} = \frac{0.12 \times 900,000}{200 + 1800} = 54 \text{ cm/year}
\]

At location - 2

\[
\frac{b}{e} = \frac{8.025}{2.25} = 3.56 \\
0.12 \times 802500 \\
\frac{Thus, x = \text{------------------------} = 47.6 \text{ cm/yr}}{225 + 1800}
\]
At location - 3

\[
\begin{align*}
&b = 8.35 \text{ km} \\
&e = 1.9 \text{ meter} \\
&0.12 \times 835000 \\
\text{Thus, } x = \frac{\text{------}}{190 + 1800} = 50.35 \text{ cm/yr}
\end{align*}
\]

At location - 4

\[
\begin{align*}
&b = 8.05 \text{ km} \\
&e = 2.2 \text{ meter} \\
&0.12 \times 805000 \\
\text{Thus, } x = \frac{\text{------}}{220 + 1800} = 47.82 \text{ cm/year}
\end{align*}
\]

The magnitude of average shore retreat calculated for the present study area (approx. 50 cm/yr) seems too high for this region. The factors which may be compensating for such a retreat are: high sediment influx from rivers, local tectonic movements, increased water load (resulting the subsidence of nearshore bottom) etc. The contributions of these factors have not been taken into consideration, which may set a sea level change rate for this locality far away from the rate adopted for the present study (1.2 mm/year).

The rate of reaction (erosion) in response to action (sea level rise) will probably depend to a large extent on the slope of the offshore bottom as per Bruun rule. Steep profiles are sensitive to short term rises in sea level than the long term rises, whereas the gentle profiles respond to longterm changes and demonstrate a pronounced phase lag (the time gap between action and reaction). In case of Paradeep, the profiles have nearshore steep part as well as an
5.2 Beach Profiles at Location No.1 & Location No.2
5.3 Beach Profiles at Location No. 3 & Location No. 4
offshore flat part. The steep part will respond to short-term fluctuations whereas the profile as a whole including the flat portion will respond to the long term rises in sea level.

The erosion rates at the beaches north of Mahanadi river may exceed the estimated rate. The explanation for this is; the longshore drift direction here is from south to north. The main river in this locality (Mahanadi) is also the major source of sediment supply. With the submergence of river mouth, the rate of sediment discharge will also come down. This gap in supply to the up-drift beaches will be filled up by increased erosion of these beaches.

Other factors and processes which may become operative to facilitate increased erosion are: increased wave attack resulting from the deepening of the nearshore bottom due to sea level rise, increased wave attack due to climatic change yielding a high frequency, duration and severity of storms in coastal waters. Sea level rise will also cause increased erosion resulting from the rise in water table, increase in rainfall or local drainage modifications rendering the beach sand wet and more readily erodible.

**Effects on Population and Land Use** : The future shorelines of one meter and three meter were projected on map prepared with the help of Census Handbook. The village wise population and land use were estimated separately for one meter and three meter rise, which are going to be affected.
### 1m Scenario in the Sub-Areas (Area in Acres)

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<th>The Sub-areas</th>
<th>No. of villages</th>
<th>Popn</th>
<th>Total Area</th>
<th>Forest Area</th>
<th>Irrigated Area</th>
<th>Non-Irrigated Area</th>
<th>Cultivable Waste</th>
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A - Total No. of villages, population and total area

B - Affected villages, population and area

C - Percentage
3 M SCENARIO IN THE SUB AREAS (AREA IN ACRES)

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</tbody>
</table>

A - Total No. of villages, population and total area
B - Affected villages, population and area
C - Percentage
Although this study employs a detailed scale of data available to arrive at a meaningful characterisation of the present level of population and land use pattern in potentially effected areas, it does not take into account the future measures, adaptive responses or the future changes in the distribution of population and land use pattern.

Here the whole village is taken as affected area even if it is intercepted partially by the projected shorelines of one and three meters respectively. That is why for the same shoreline the total area affected, calculated village wise is more than the area going to be submerged.

The area that might be inundated in the low scenerios (one meter) represents approximately 23-24 per cent land of the study area, which contain 10.2 per cent of the estimated population of the area inhabited in 96 villages. The area that could be lost by flooding in the three meter scenerio represent about 58-59 per cent area inhabited by 41.37 per cent of the total population in 488 villages.

Nearly 66 per cent land of the study area is presently being cultivated (amounting 274533 acres) out of which 13.27 per cent will be submerged with the low scenerio and 52.47 per cent cultivable land for a three meter scenerio (these figures do not include cultivable wastelands). In this area rice accounts bulk of the total grain output of the net cropped area. It accounts more than 90 per cent land in
### 1m and 3m Scenarios for the whole study area

(Area in acres)

<table>
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<th>No. of Villages</th>
<th>Pop $^n$</th>
<th>Total Area</th>
<th>Forest Area</th>
<th>Irrigated Area</th>
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</table>

A - Total No. of villages, population and total area

B - Affected villages, population and area

C - Percentage
the Kharif season and 28 per cent in the Rabi season. It will be difficult to imagine and replace the loss of croplands due to sea level rise because the area is already extensively cultivated. The cultivable waste areas which will remain unaffected even after a three meter rise is a negligible area (11548 acres) to compensate for the loss of total croplands which amounts 134939 acres. Adoption of strategies of intensive cropping and land utilisation may bring some promise as a compensation for the loss of agricultural lands.

Again an additional amount of agricultural land may become unsuitable for cultivation as the saltwater would transgress further landward with the encroachment of sea water over the land.

The major town in this area are Ersama, Mahakalpara, Tirtol, Patkura and Paradeep which also form the nuclei of relatively densely populated areas. Out of these, with the one meter level rise, Paradeep would be the only and most affected town area. More than 80 per cent of the area will be directly affected with the one meter rise and the rest would be submerged under the three meter rise. But for population and land use study, whole Paradeep is considered to be affected with the one meter rise.

With the three meter rise, two more towns i.e. Mahakalpara and Ersma will be submerged. However, Tirtol and Patkura will remain unaffected in these scenarios.
Location of major towns with respect to future shorelines of 1 m & 3 m.
The amenities like storage, transport, communication trade and services, power, water, sanitation etc. are assumed to be distributed as population in this area. These activities and installations will also get affected due to sea level rise in a scale more or less same as population. The one meter rise would submerge 2 km of the Kendrapara canal which runs E-W in the north of the study area and an additional 8 km with the three meter rise. The other major canal which is to be affected is Taladanda canal running E-W at the centre of the study area will loose about 0.5 km and 5 km respectively with one and three meter rise in sea level. The NH-5 which joins Daitari and Paradeep is also known as Express Highway. Of this highway 6 km and 21 km will be affected with the one and three meter rise respectively. Paradeep is also connected with Cuttack by SE Railway’s Cuttack-Paradeep branch. It would also be affected with 8 km and 14 km with the rises of one and three meter respectively.

REFERENCES


6. Ibid.


