

Hazard Line Mapping of Mahanadi Delta Odisha using Remote Sensing and GIS

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ABSTRACT: It is estimated that one third of the world's population are living in the coastline and their livelihood depends on the resources available from it. Mahanadi Delta in India is a coastal region located in the state of Odisha. Mahanadi Delta in India is formed by the network of three major rivers, Mahanadi, Brahmani and Baitarani draining to Bay of Bengal. The delta covers a coastline length of 200km, which stretches from south near Chilika lake to north up to Dhamra river. The population density is high in the upper part of Mahanadi Delta and gradually declines towards the coast. Compared to west coast of India east coast is more prone to cyclones. When compared to other eastern coastal states in India Odisha is the worst affected state with highest number of cyclonic storms per year crossing its coast. The various hazards affecting the coastline of Mahanadi Delta are erosion, accretion, cyclones, storm surge and extreme events like tsunamis. These hazards lead to severe loss of human life, damage to properties and to ecosystem. In order to safe guard the people and their properties, hazard prone areas should be demarcated. A newly adopted method is based on mapping a composite hazard line considering all the hazards such as coastal erosion and accretion, storm surges, cyclones, tsunamis and high tide line in an integrated way. This hazard line will act as a precautionary boundary and assist protection and development activities in the earmarked zone.

I. INTRODUCTION

A. GENERAL

Mahanadi Delta is located in the state of Odisha in east coast of India. In India coastal areas are heavily populated and more than three hundred million people, or nearly 26% of the total population live in the coastal zone. East coast of India is vulnerable to erosion, accretion, cyclones, storm surges and

tsunami. Among the states of east coast Odisha is more vulnerable to these hazards. This deltaic coast is vulnerable to natural hazards like cyclones and storms apart from high river floods. When compared to other eastern coastal states in India, Odisha is the worst affected with highest number of cyclonic storms crossing its coast during the pre-monsoon and post monsoon period. Depending on the intensity of cyclone, storm surge 6-7m high may enter the coast accompanied by heavy to very heavy rainfall. Due to the impact of cyclone the people along the coast are affected badly. Many of them loose their properties. Human and livestock loss is equally high. So hazard line mapping will be useful for taking precautionary steps to reduce the damages arising from the hazard.

The aim of this project is to delineate the hazard line mapping for Mahanadi delta of Odisha state.

The main component required to complete the above aim include mapping of shoreline, flood line and current Land use for this project site.

Shoreline mapping is done to access the shoreline change of MahanadiDelta. This is done by assessing shoreline change rate from the past satellite data using satellite data (1990, 2000, 2010, 2011) satellite image with 1972 SOI toposheet 73L11 sensing as the base map.

Flood line mapping is done to delineate the flood line for a return interval of 1 in 100yrs using GeographicInformation System (GIS). To mark the maximum 100yrs flood level of Mahanadi delta. Tide level data from

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Global Sea Level Observing System (GLOSS) is used and flood line will be marked using SRTM Digital Elevation Model (DEM).

Land use mapping is done by interpreting the 2011 satellite imagery. The scale of the satellite imagery is uniformly kept as 1: 50000.

II. STUDY AREA

A. INTRODUCTION

In the land ocean interaction zone, river deltas are formed due to dynamic interaction of fluvial and marine agencies on the coastal margin. Delta building varies depending upon geologic, tectonic, geographic, climatic and environmental settings. Major deltas in India occur on the Bay of Bengal coast on the eastern part. Mahanadi river delta is one among them.

B. GEOGRAPHIC LOCATION

The Mahanadi river delta lies between 85°40':86°45'E and 19°40':20° 35'N and it covers an area of 0.9×10⁴ km². The catchment area of river covers an area of 1.42×10⁵ km². The climatic condition of Mahanadi delta is tropical with hot and humid monsoonal climate. The average rainfall rate of Mahanadi delta is 1572mm, about 70% is precipitated during the southwest monsoon between Mid- June to Mid- October. After traversing a long distance of over 800km Mahanadi river starts building up its delta plain from Naraj where the undivided Mahanadi branches forming its distributary system ramifying in the delta plain area.

Study area map is shown in Figure 1 and the delta along with its tributaries is shown in Figure 2



Figure 1 Study area map, Mahanadi delta

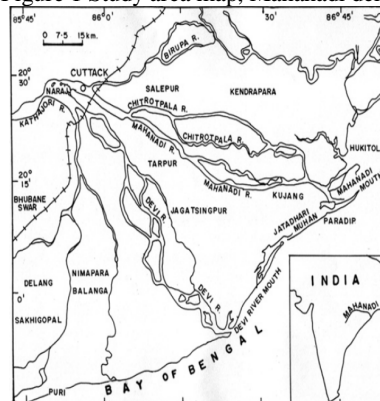


Figure 2 Mahanadi delta with its tributaries

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III. METHODOLOGY

A. INTRODUCTION

The various steps involved in hazard line mapping are

- Shoreline mapping
- Demarcating the flood line
- Mapping of land use

Combination of shoreline and flood line will give us hazard line, then land use pattern of that area will be marked and then the hazard line and land use pattern will be compared, so that it gives an idea about the various land use pattern which will get affected in the near future

B. SHORELINE MAPPING

Shoreline mapping is a technique of mapping the shoreline of a coast to understand whether the coast is eroding or accreting. For this, LANDSAT image of past 4yrs (1990, 2000, 2010, 2011) and toposheet of Survey of India 1972 will be taken for geo referencing the satellite imagery. The software used for geo referencing is ERDAS using 1972 SOI toposheet as the base year. Then the shoreline of Mahanadi delta will be digitized using ArGIS software using 1990, 2000, 2010 and 2011 satellite imagery.

The Digital Shoreline Analysis System (DSAS) as defined by U.S. Geological Survey (USGS) is used to determine the rate of change of the shoreline for Mahanadi delta. This method computes rate of change statistics from multiple historic shoreline positions. The created layers of multi-date shorelines (1972, 1990, 2000, 2010, 2011) were used as an input for DSAS model to calculate the rate of change since 1972 for a period of 39yrs. Baselines were created at approximately 2km landward of the 1972 shoreline but did not include the small creeks and areas such as river mouths and spits. Then DSAS will create transects perpendicular to baseline, 200m apart. With reference to the baseline, seaward shift of the shoreline along the transect is considered as positive while landward shift is considered as negative. Positive value denotes accretion and negative values indicate erosion. The rate of shoreline variations were calculated using Linear Regression Method (LRR) in the ArcGIS environment to identify the erosion and accretion areas along the Mahanadi delta.

A minimum of 4 shoreline years at each DSAS transect were used for the calculation of rates of shoreline change. Rates were not calculated at

- River mouths/ creek openings
- Ports, harbours and
- Other coastal structures (seawalls/ ripraps)

Seven different classes for shoreline change have been considered depending upon the erosion and accretion rate. The detail is given in Table I

Table I Erosion and accretion rate

VALUES (m/yr)	EROSION / ACCRETION
<-5	High erosion
-5 to -2	Medium erosion
-2 to -0.5	Low erosion
-0.5 to +0.5	Stable coast
+0.5 to +2	Low accretion
+2 to +5	Medium accretion
> +5	High accretion

(Saxena et al., 2011)

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A brief methodology for shoreline mapping is given in Figure 3

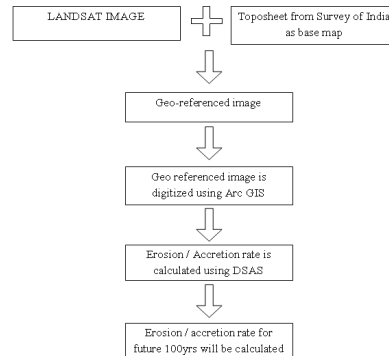


Figure 3 Methodology for shoreline mapping

A. DEMARCATING THE FLOOD LINE

Flood hazard mapping helps identifying coastal areas that are at risk of flooding under extreme conditions. This include storm surges, cyclone and flood from rivers. Hazard line mapping define potential to harm using the return intervals. The return period for each flood is computed from the past events. It is then predicted into the future through extrapolation; using statistical distributions (i.e. the 100year flood data computed from the past 20year data from Paradip Port tide gauge data).

Return interval is otherwise known as recurrence interval. It is an estimate of the interval of time between events of flood or river discharge flow of a certain intensity or size. It is a statistical measurement denoting the average recurrence interval over an extended period of time, and is usually required for risk analysis.

Different formulas are used for finding out the return period. Some important formulas used for finding the return period for the extreme flow level are as follows.

If the annual water level of 'n' years are arranged in descending order , then there will be some figure at serial order at 'm'. Then it can be said that, this water level at 'm' or more than this will occur in 'm' out of 'n' i.e., m/n. The recurrence interval can be calculated by,

California Formula $Tr = n/m$ Eqn (1)

Hazens Formula $Tr = n/m-0.5$Eqn (2)

Weibull's Formula $Tr = n+1/m$ Eqn (3)

Gumbel's Formula $Tr = n/(m+C-1)$Eqn (4)

In Gumbel's formula C is the correction factor. Its value depends on m and n as given in the Table II

Table II Values used for Gumbel's formula

m/n	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.04
C	1	0.95	0.88	0.845	0.78	0.73	0.63	0.59	0.52	0.4	0.28

The T_r values of all four are compared and the value which comes near to 1 is considered. Then using the corresponding formula 1 in 100yr data is calculated. Along with it Annual Mean Sea Level Trend and Projected Sea Level Rise due to Global Warming is added. This will give 1 in 100yr flood level.

Contours are created in Digital Elevation Model (DEM) for this value. This contour is then transferred to LANDSAT image and floodline is created. DEM is derived from Shuttle Radar Topographic Mapping (SRTM).

A brief description of demarcating flood line for 1 in 100years is given in Figure 4

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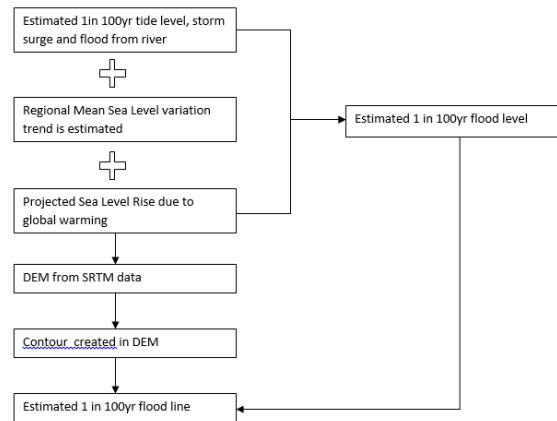


Figure 5 Methodology for floodline mapping

B. MAPPING OF LAND USE PATTERN

Land use pattern can be defined as the method to study the various land use of a particular area. The LANDSAT image will be geo referenced using toposheet as base map with ERDAS software. Then the geo referenced image will be used for marking the land use pattern. Then the various features were digitized using ArcGIS through on-screen interpretation of the online imagery. The various key interpretation factor that are considered for delineating the land use pattern are size, shape, tone, colour, texture and pattern.

A brief description of Land use pattern is given in Figure 6

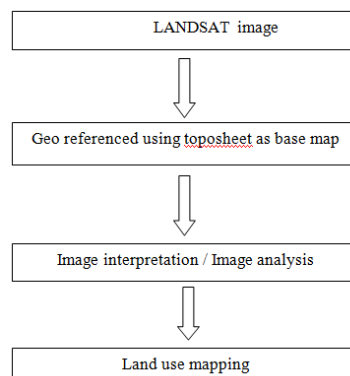


Figure 6 Methodology for mapping Landuse

C. HAZARD LINE MAPPING

Hazard line can be defined as an imaginary boundary line parallel to the coast in the landward direction, few kilometers away. The seaward side to the hazard line is prone to the impacts of cyclones, storm surges, erosion and even extreme events like tsunami. The landward side of the hazard line is considered as safer zone. This imaginary line which separates the two zone is called hazard line.

Hazard line mapping is a combination of shoreline mapping and floodline mapping. The maximum values of predicted 100year erosion and floodline will give the hazard line.

A brief description of hazard line mapping is shown in Figure 7 and Figure 8

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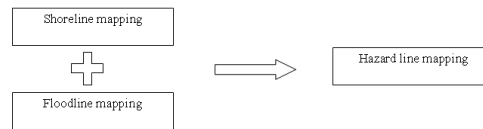
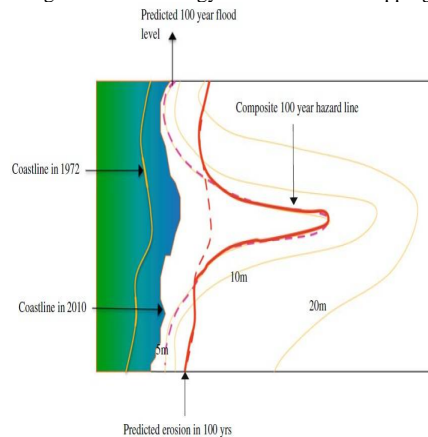


Figure 7 Methodology for Hazard line mapping



(Saxena et al., 2011)

Figure 8 Sketch of Hazard line mapping

IV. CONCLUSIONS

A. SHORELINE MAPPING

Shoreline mapping of Mahanadi Delta is done to calculate the erosion/ accretion rate and there by predicting the rate after 100yrs. For this LANDSAT image of 5yrs (1972, 1990, 2000, 2010, 2011) is geo referenced using 1972 toposheet as base map. Shoreline for each of these 5yrs is digitized. To get a clear picture of digitized image, shoreline is split into 3 parts based on river mouths. The digitized shoreline image is shown in Fig 9 to Fig 11

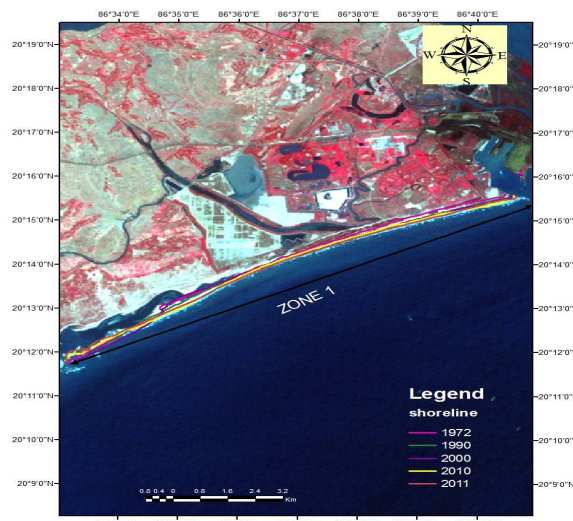


Fig 9 Digitized shoreline image of zone 1

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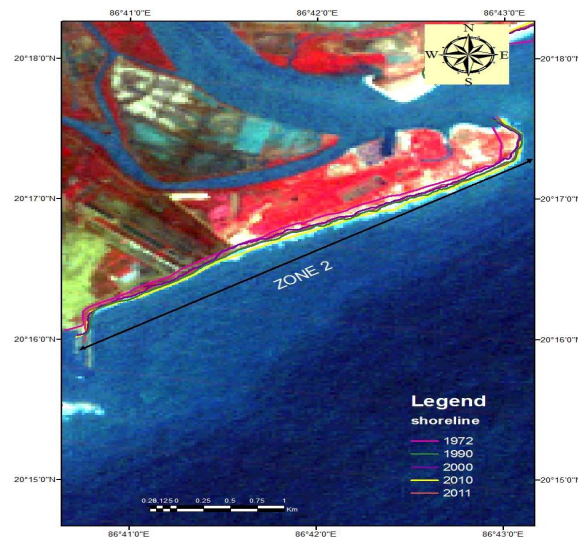


Fig 10 Digitized shoreline image of zone 2

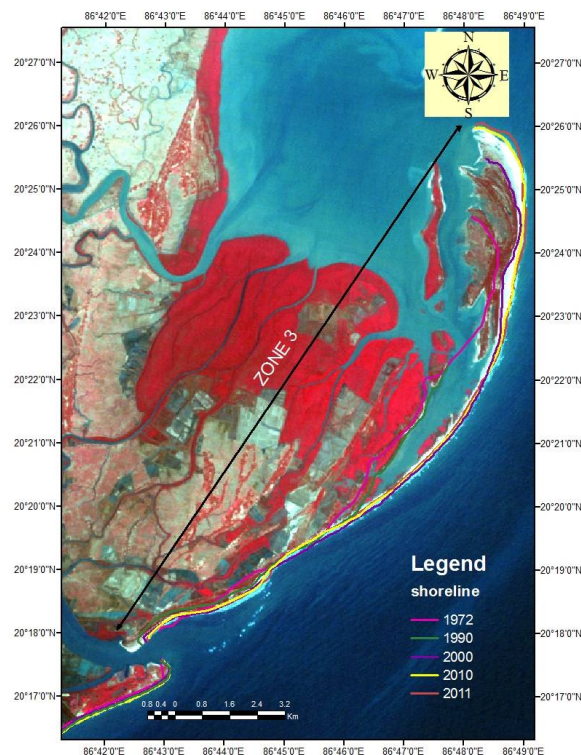


Fig 11 Digitized shoreline image of zone 3

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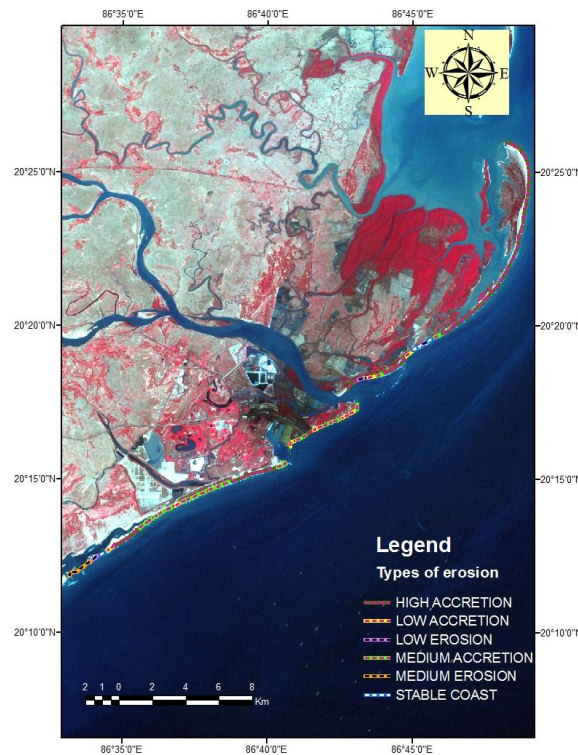


Fig 12 Type of erosion along the coast

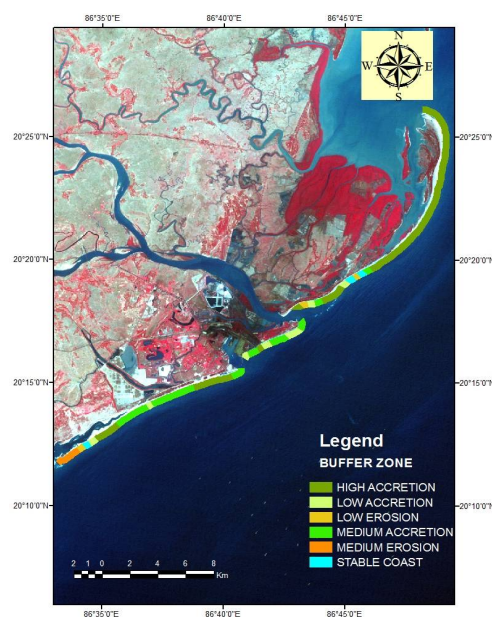


Fig 13 Buffer zone along the coast

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Predicted 100yr erosion is calculated using LRR (Linear Regression Rate) method. Predicted 100yr erosion is shown from 14 to 15 by dividing the area into three zones for clear interpretation

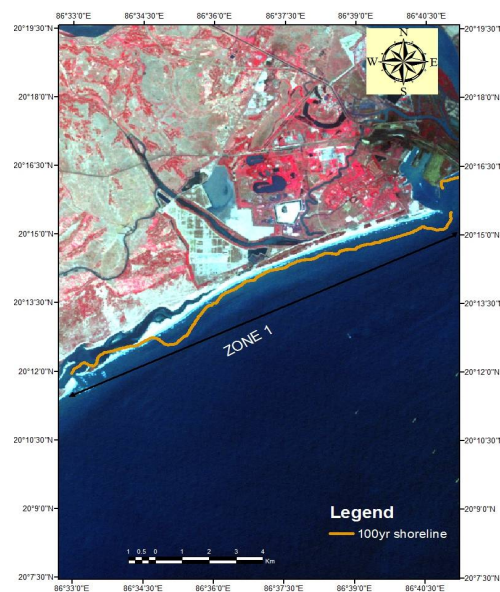


Fig 14 100yr shoreline for zone 1

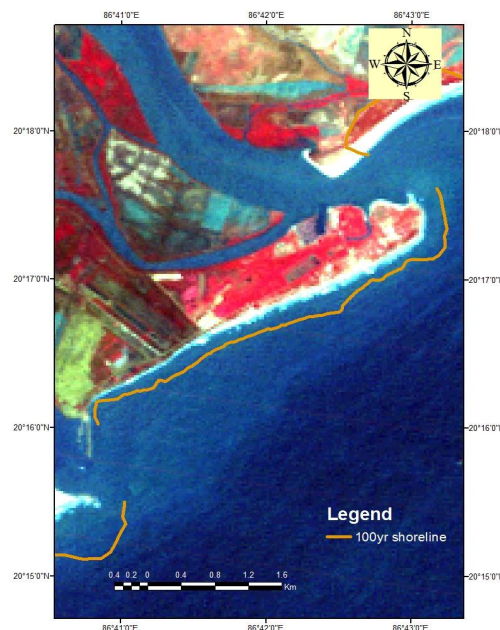


Fig 15 100yr shoreline for zone 2

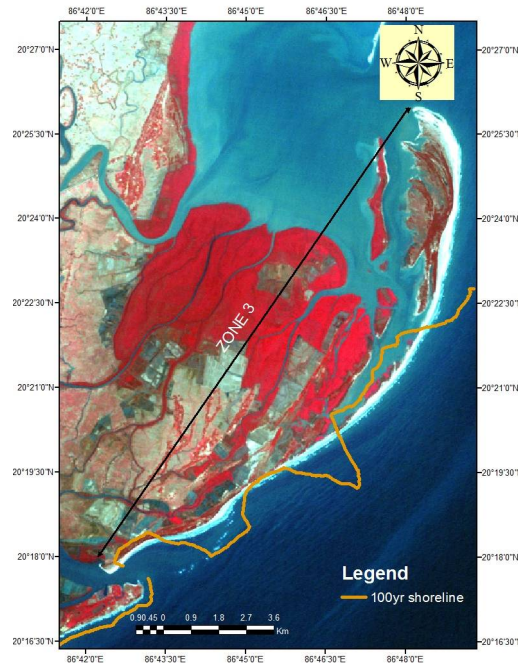


Fig 16 100yr shoreline for zone 3

Major portion of Mahanadi Delta is accreting. The starting portion of selected area and the area near Mahanadi river is slight eroding all other regions are accreting.

B. FLOODLINE MAPPING

The factors considered here for floodline mapping are past 20yr Tide Level Data, Annual Mean Sea Level Trend and Projected Sea Level Rise due to Global Warming.

Return period is calculated using statistical method. The methods adopted are California Formula, Hazen's Formula, Weibull's Distribution and Gumbel Distribution. For more accuracy the distribution whose value which comes near to 1 will be considered.

While comparing the four distributions it is clear that the value for Gumbel distribution and Hazen's formula comes near to 1, so here Gumbel's distribution is considered. So using Gumbel Distribution maximum flood level is calculated.

Gumbel's distribution

As per this distribution, the probability of occurrence is given by,

$$P = 1 - \exp[-\exp(-y)] \quad \text{.....Eqn (5)}$$

Where P = Probability (1/Tr)

y = Reduced Variate (Dimensionless number)

$$1 - p = \exp [-\exp (-y)]$$

$$1 - 1/T_r = \exp [-\exp (-y)]$$

$$\exp [-\exp (-y)] = T_r - 1/T_r$$

Take Logarithms of both sides

$$-\exp (-y) = \log_e T_r - 1/T_r$$

$$\exp (-y) = -\log_e T_r - 1/T_r$$

$$= 2.303 \log_{10} T_r - 1/T_r$$

$$= 2.303 \log_{10} T_r / T_r - 1$$

Again taking Logarithms on both sides

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$$y = -[0.834 + 2.303 \log_{10} (\log_{10} T_r / T_r - 1)] \dots \text{Eqn (6)}$$

We have, $p = 1 - \exp[-\exp(-y)]$

The reduced variate $y = a(x - x_f)$

Here 'a' and 'x_f' are the parameters of the distribution

$$a = \sigma_n / \sigma$$

$$x_f = -[\bar{x}_n / \sigma_n] \sigma$$

Where,

\bar{x}_n = Mean

σ = Standard deviation

\bar{x}_n = Reduced Mean

σ_n = Reduced Standard deviation

The Reduced Mean \bar{x}_n and Reduced Standard Deviation (σ_n) depends on n. These values are given in Table III

Table III Estimation of Reduced Mean and Reduced Standard Deviation

n	σ_n	Reduced Mean
10	0.9497	0.4952
12	0.9833	0.5035
14	1.0095	0.5100
16	1.0316	0.5157
18	1.0493	0.5202
20	1.0629	0.5235
22	1.0754	0.5268
24	1.0864	0.5296
26	1.0961	0.5320
28	1.1047	0.5343
30	1.1124	0.5362
32	1.1193	0.5380
34	1.1255	0.5396
36	1.1313	0.5410
38	1.1363	0.5424
40	1.1413	0.5436

$$Y_T = a(x_T - x_f) \\ = \sigma_n / \sigma [x_T - (\bar{x}_n / \sigma_n) \sigma]$$

$$y_T \sigma / \sigma_n = [x_T - (\bar{x}_n / \sigma_n) \sigma]$$

$$x_T = y_T \sigma / \sigma_n + \bar{x}_n \sigma / \sigma_n$$

$$x_T = \sigma [y_T + \bar{x}_n / \sigma_n]$$

$$X_T = \sigma [y_T + \bar{x}_n / \sigma_n] \dots \dots \dots \text{Eqn (7)}$$

Where, K_T - frequency factor = $Y_T - \bar{x}_n / \sigma_n$

In this case,

The number of sample $n = 20$

Mean $\bar{x}_n = 1.5455$

Standard Deviation $\sigma = 0.3678$

From Table,

Reduced Standard Deviation, $\sigma_n = 1.0629$

Reduced Mean $\bar{x}_n = 0.5235$

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For return period $T_r = 100\text{yrs}$ $Y_T = -[0.834 + 2.303\log_{10}(\log_{10} 100/100-1)] = 4.6012$
From Eqn 5.3 $x_T = 1.5455 + [4.6012 - 0.5235/1.0629] 0.367$ $x_T = 3.05$
From the analysis of extreme water level data through Gumbel distribution it is concluded that 1 in 100yr return interval for the tide level is estimated to be 3.05m from the MSL.

While considering 1 in 100yr flood level Mean Sea Level Trend and Projected Sea Level Rise is also considered.

Regional Sea Level Rise

Annual mean sea level data for Paradip coast is obtained from Survey of India (S.O.I). The regional mean sea level variation trend was estimated by taking the average of all these values. The regional sea level rise was estimated as 0.04911m for 100yrs. Annual MSL trend for Paradip is shown in Table IV

Table IV Annual MSL trend for Paradip

No of years	Data Interval	Trends/year	Projection for 100year
83	1921 to 2004	0.4911mm	0.04911m

Projected Sea Level Rise due to global warming

Projected sea level rises of 0.59m for the year 2100 corresponding to AIFI scenario of IPCC(2007) was considered for the estimation of total sea level rise.

Worst case scenario of adding local/global sea level rise for estimation of 1 in 100yr flood level

The 1 in 100yr flood level was estimated by adding all the three components mentioned above

$$\text{Extreme Flood Level} = 3.1 + 0.0491 + 0.59 \\ = 3.69\text{m}$$

From the study it is concluded that for 1 in 100yr return interval the extreme events may cause the maximum run up of water to an elevation of 3.69 m

The projected floodline i.e 3.69 m was transferred to Digital Elevation Model as a contour and this will be transferred to LANDSAT image to create the floodline

Digital Elevation Model is shown in Fig 17

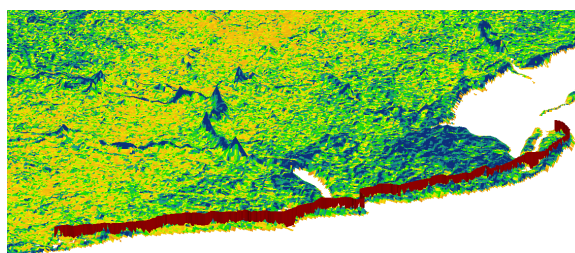


Fig 17 Digital Elevation Model

Floodline for Mahanadi delta is shown from Fig 18 to 20

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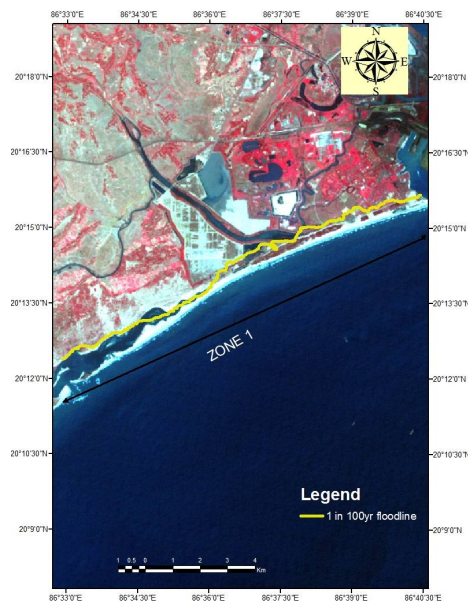


Fig 18 1in 100yr floodline for zone 1

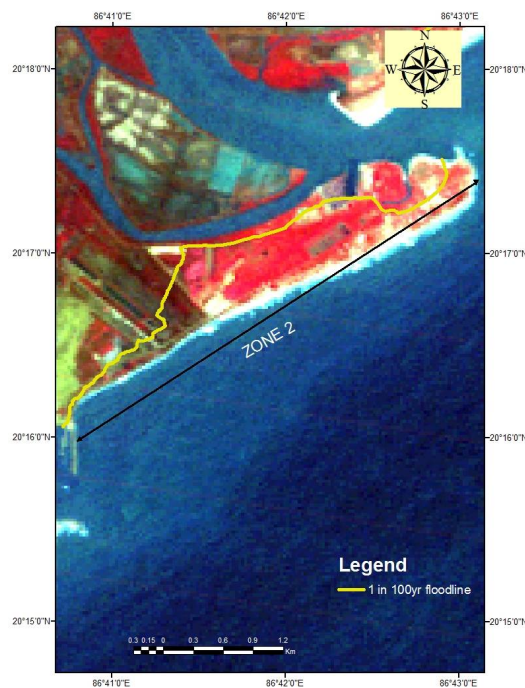


Fig 19 1in 100yr floodline for zone 2

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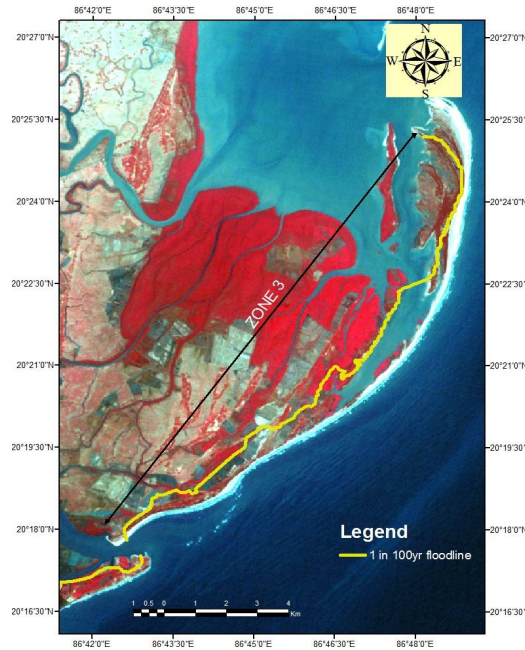


Fig 20 1 in 100yr floodline for zone 3

C. HAZARD LINE MAPPING

Hazard line will act as a precautionary boundary and assist protection and development activities in the earmarked zone. It is a combination of erosion line and flood line. The most landward of two line will give the hazard line. It represents the worst case – margin of safety. Formation of Hazard line is shown in Fig 21 and Hazard line of Mahanadi delta is shown from Fig 22 to Fig 24



Fig 21 Formation of Hazard line

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Fig 22 Hazard line mapping of zone 1

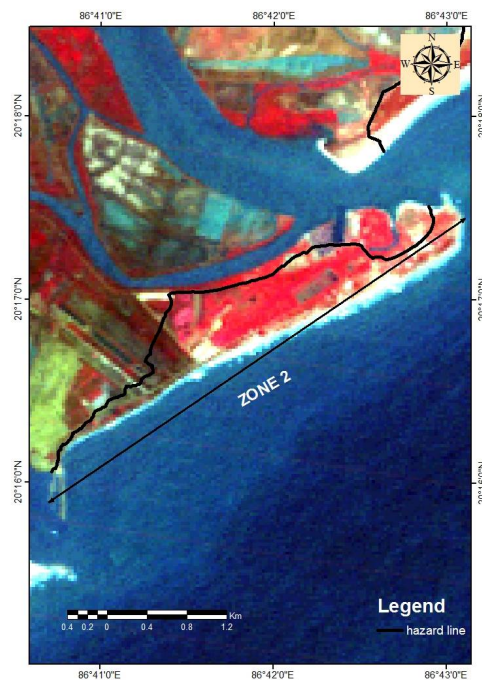


Fig 23 Hazard line mapping of zone 2



Fig 24 Hazard line mapping of zone 3

D. LANDUSE

Mapping of landuse will help us to understand what all are the areas that are going to get affected in the future. The areas coming under the hazard line are areas going to get affected. It will also help the coastal managers to plan activities to protect the threatened areas. The land use pattern of Mahanadi delta is shown in Fig 25 and Fig 26 which shows the areas that are going to get affected. The areas coming on the seaward side of hazard line are under threat.

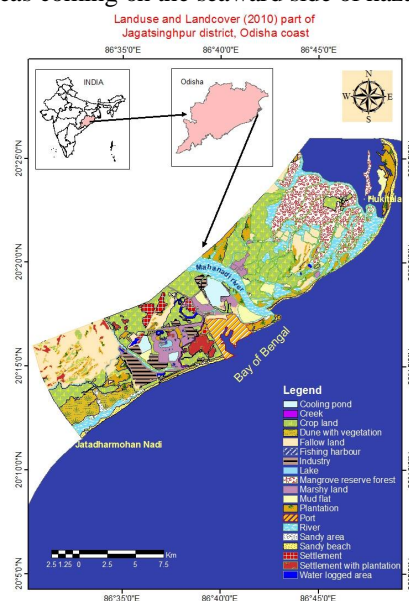


Fig 25 Landuse of Mahanadi delta

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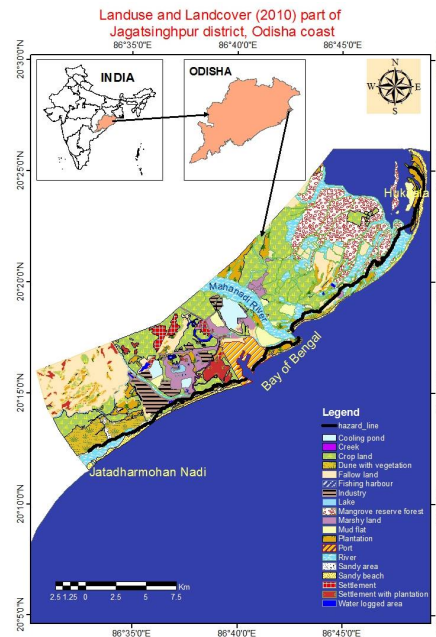


Fig 26 Landuse of Mahanadi delta along with Hazard line.

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