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Long-Term Coastal Evolution Based on Comparison of Inferred Paleo Shoreline and Present Shoreline Along the Mahanadi Tri-Delta Coast, Eastern India.

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KEYWORDS

Paleo shoreline reconstruction, Present shoreline change, Delta progradation, Digital Shoreline Analysis System (DSAS), Coastal evolution, Mahanadi tri-delta coast.

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Abstract

Over the millions of years, the Mahanadi delta prograded and marched towards sea with the evolution of various coastal units such as older deltaic plains, younger deltaic plains, older coastal plains and younger coastal plains and their various landforms. Annually, the Mahanadi River contributes a significant amount of sediment to the coastal environment, discharging approximately 49.0 ± 20.5 km^3 of water and 17.4 ± 12.7 × 10^6 tons of sediment into the Bay of Bengal.Specifically, it helps to understand the rate of delta growth and coastal migration towards sea over the time scale. And by comparing the former and the present position helps to understand the sediment redistribution and coastal evolutions and their patterns.In light of this, the study aims to reconstruct the paleo shoreline position and analyse with the present shoreline position and to compare the long-term coastal evolution along the study area. The inferred paleo shoreline covers a distance of 157.74 km along the inland parallel to the coast.

The results show that the paleo shoreline has been displaced up to 80 km towards sea and the combined prograded landform area meets 7494.67 sq km. For understanding the long-term shoreline change trend, the study uses the 59 years dataset from 1965 to 2024. Using Digital Shoreline Analysis System (DSAS), shoreline change analysis were performed with 3452 transects along 71 km.Over the 59 years, the result shows that southern sector is dominated by the accretion with local erosion, the central sector is redistributed between erosion and accretion and the northern sector is dominated by the continuous erosion. The overall behaviour of the modern sectors clearly shows that the coast is not continuously receiving the sediment from river source which results in localized erosion and accretion and hence it is not uniformly prograding in recent years compared to past delta progradation.

1 Introduction

Coastlines are the dynamic features which are controlled by fluvial, aeolian and marine forces and erosion and accretion are the geomorphic response of such geomorphic agents. Such processes evolve the coastal landform over the years. Among various geomorphic features, delta plays an important role in contributing the coastal landform. At the same time river plays a significant role in bringing the sediment continuously from continental inland and depositing at the fluvial and coastal depositional regions and over the years the sedimentation results in the formation of delta. However, the growth of the delta apex is purely controlled by the river and its sediment supply and further these delta margins are reworked by the coastal process and result in formation of various landforms (Wright & Coleman, 1973; Galloway, 1975; Komar, 1998; Masselink et al., 2011; Bird, 2008; Bloom, 2003; Summerfield, 1991; Dean & Dalrymple, 2002; Bhattacharya & Giosan, 2003; Das & Maejima, 1996).

Similarly, over the millions of years the Mahanadi delta prograded and marched towards sea with the evolution of various coastal units such as older deltaic plains, younger deltaic plains, older and the younger coastal plains and their various landforms (Das & Maejima, 1996; Somanna et al., 2016). Annually to support and to contribute the sediment source to various landforms, Mahanadi River discharges 49.0 ± 20.5 km^3 of water and 17.4 ± 12.7 × 10^6 tons of sediment to the Bay of Bengal (Bastia &Equeenuddin, 2016). Present coast holds various dynamic features such as spits and ridges and various beach morphology and these dynamic features are controlled by the alongshore currents,and sea level rise.Specifically, the dynamic shoreline is constantly influenced by waves, tides, currents, sediment supply and storm events. They shift the shoreline position landward (accretion) or seaward (erosion) over the time. By assessing such instability helps to understand the evolutions over time which directly support the coastal management (Roy et al., 2018; Murali et al., 2015). Additionally, along with the present shoreline information, the position of paleo shoreline feeds the insights about the coastal migration and evolutions over the time. Such reconstruction of past and the present shoreline positions and their evidential change helps to understand the delta progradation, sediment supply and the long-term coastal evolutions (Dash et al., 2020).

Paleo shoreline represents the past shoreline position and by identifying their former position helps to understand how far the land has been migrated towards sea. Specifically, it helps to understand the rate of delta growth and coastal migration towards sea over the time scale. And by comparing the former and the present shoreline position helps to understand the sediment redistribution and coastal evolutions and their patterns (Das & Maejima, 1996; Dash et al., 2020; Somanna et al., 2016).Many researchers have worked on geomorphology of the Mahanadi delta, paleo strandlines and paleochannels, delta progradation and shoreline changes along the Odisha coast (Das & Maejima, 1996; Somanna et al., 2016; Dash et al., 2020; Roy et al., 2018; Murali et al., 2015). But this clearly insists that most of the work has been carried out separately on paleo and present shoreline investigation. But only few worked on comparative of paleo and modern evolutions and that comparison mostly helps to understand the sequence of delta progradation, sediment redistribution and long-term coastal evolution between the inferred paleo and the present position.In light of this the study aims to reconstruct the paleo shoreline position and analyse it with the present shoreline position and to compare the long-term coastal evolution along the study area. This comparative analysis helps to provide the insights of long-term delta progradation and recent coastal behaviour along the Mahanadi delta coast.

2 Study Area

The Mahanadi delta is located at the east coast of India along the Odisha central coast. The Mahanadi delta is fed by the Mahanadi River which runs from west with the total distance of 851 km, of which 357 km lies in Chhattisgarh and 494 km lies in Odisha, and empties into the Bay of Bengal. The Mahanadi is the second largest peninsular river in flood generating capacity and water availability next to the Godavari River in India. The study area also covers the part of Brahmani and Baitarani deltaic coast forming the tri-delta region (Figure 1).

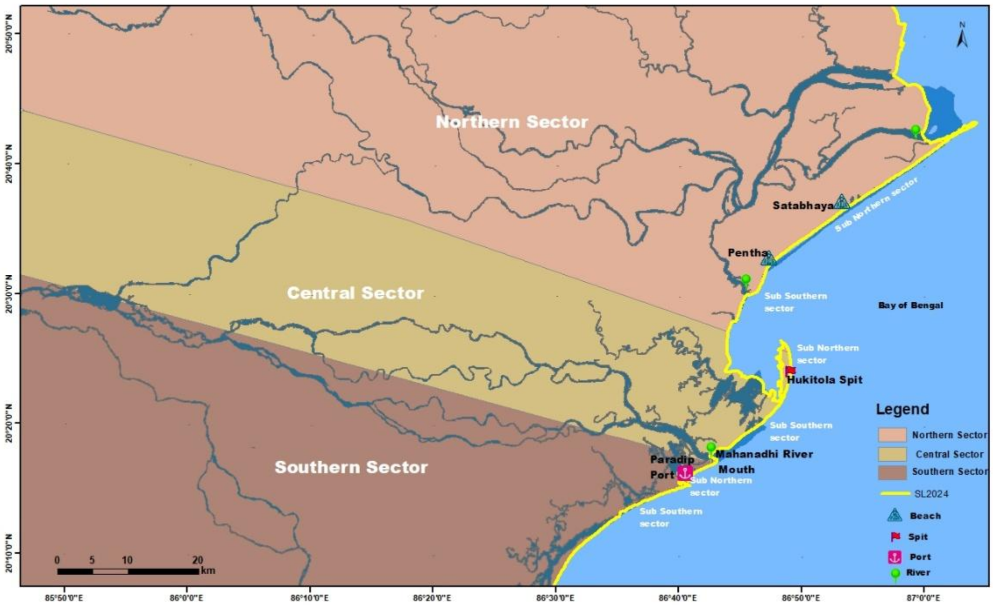

Figure 1 Study area location along the Mahanadi delta coast, eastern India.

Over the millions of years the Mahanadi delta prograded and marched towards the sea with the evolution of various coastal units such as older deltaic plains, younger deltaic plains, older coastal plains and younger coastal plains and their various landforms (Das & Maejima, 1996; Somanna et al., 2016). Annually the Mahanadi River contributes a significant amount of sediment to the coastal environment, discharging approximately 49.0 ± 20.5 km^3 of water and 17.4 ± 12.7 × 10^6 tons of sediment into the Bay of Bengal (Bastia &Equeenuddin, 2016).The present coast holds various dynamic geomorphic features such as spits, ridges and beach morphology, and these dynamic coastal landforms are controlled by seasonal currents, extreme events and sea level rise.

The inferred paleo shoreline covers a distance of 157.74 km along the inland parallel to the coast and lies between pediplains and the deltaic older coastal plains. Based on the morphological discontinuity, the study area was divided into three sectors namely the southern sector, central sector and northern sector.The southern sector is bounded between the tidal inlet at the south and the Mahanadi River mouth at the north and covers a distance of 54.8 km along inland. The central sector is bounded by the Mahanadi River mouth at the south and open coast at the north and covers a distance of 24 km along the inland paleo shoreline. The northern sector is bounded by the river mouth at the south and bathymetry at the north and covers a distance of 77.54 km.

Present shoreline analysis along the study area covers a coastal stretch of 71 km, which was divided into southern, central and northern sectors based on the morphological discontinuity due to geomorphic interruptions.

3 Materials and Methodology

3.1Paleo Shoreline Identification

For understanding the recent coastal deposits during the Quaternary period (sourced from Geological Survey of India GSI), the inferred paleo shoreline was digitized as the transitional boundary between the continental erosional landscape and coastal depositional environment based on the geomorphological map showing coastal origin and geological map showing age prepared by Geological Survey of India (GSI) (Figure 2).

To demarcate the paleo shoreline, the boundary between pediplains with alluvial plains and deltaic coastal plains was marked as an inferred paleo shoreline. The pediplain was considered as a continental erosional landform representing the continental terrain, whereas the deltaic plains were considered as fluvial and coastal depositional region formed by the Mahanadi River.

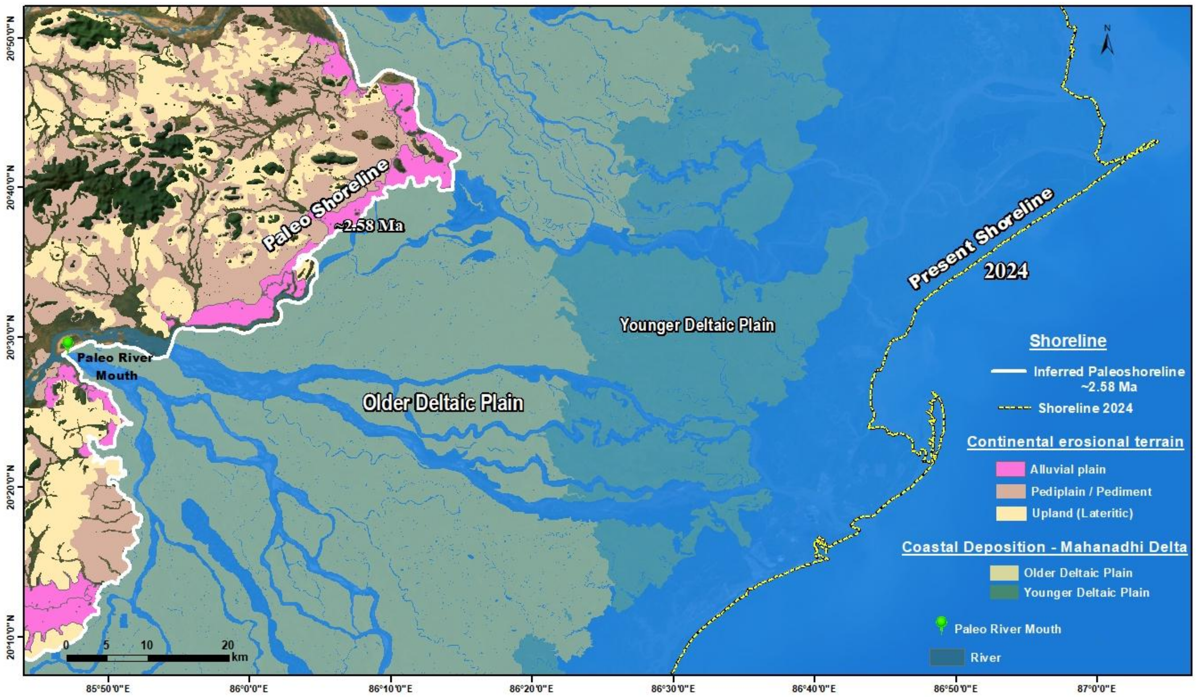

Figure 2 Geomorphology and inferred paleo shoreline of the study area

3.2Sector Classification and Transect Generation

The inferred paleo shoreline covers a distance of 157.74 km along the inland parallel to the coast. Based on the morphological discontinuity the study area was divided into three sectors namely southern sector, central sector and northern sector.The southern sector is bounded between tidal inlet at the south and the Mahanadi River mouth at the north and covers a distance of 54.8 km along inland. To calculate the shoreline displacement using DSAS, transects of around 18 were generated across the sector between the paleo and the present shoreline.The central sector is bounded by Mahanadi River mouth at the south and open coast at the north and covers a distance of 24 km along the inland paleo shoreline. To calculate the shoreline displacement using DSAS, transects of around 11 were generated along the 24 km cross the inland between the paleo and the present shoreline.The northern sector is bounded by river mouth at the south and bathymetry at the north and covers a distance of 77.54 km. To calculate the shoreline displacement using DSAS, transects of around 12 were generated along the 77.5 km cross the inland between the paleo and the present shoreline.So for the analysis total 41 transects were used. Paleo displacement was very large and transects placed too densely between the paleo and the present shoreline become difficult which have caused the intersection problem, therefore selected 41 transects were used for the paleo and present shoreline change analysis. Separate sets of transects were generated for the paleo shoreline analysis and the present shoreline change analysis.

3.3Analysis Extent for Paleo and Present Shoreline

For large paleo–present shoreline displacement analysis, the distance between the inferred paleo shoreline and the present shoreline was more than 80 km. If the analysis is limited for short distance, the transects could intersect incorrectly and fail to cross both shoreline positions properly.In order to avoid these technical issues, the long coastal stretch of about 157 km was selected to maintain stable transect geometry, ensure proper intersection and to avoid overlaps. This is a technical DSAS requirement when analysing large shoreline displacement.Since the paleo analysis aims to understand the delta progradation and coastal evolution, the analysis must cover the entire deltaic coastal belt. This represents delta-scale shoreline displacement and helps to measure the regional progradation pattern.

3.4 Present Shoreline Proxy and Shoreline Extraction

For present shoreline extraction, satellite imagery was used to identify the shoreline position along the study area. The shoreline was digitized from the satellite images in GIS environment (McCurdy, 1950; Stafford & Langfelder, 1971).

The shoreline proxy used for shoreline extraction was the wet–dry boundary visible along the beach which represents the shoreline position. This boundary represents the limit between the land and water interface and was used as the shoreline indicator for digitization (Crowell et al., 1991; Zhang et al., 2002).Multi-temporal shoreline positions were extracted for shoreline change analysis. The earliest shoreline was obtained from CORONA satellite imagery of the year 1965 and the most recent shoreline position was extracted from LISS-IV satellite imagery representing the present shoreline condition.All shoreline positions were digitized in GIS environment and used as input shoreline datasets for Digital Shoreline Analysis System (DSAS) to calculate shoreline change statistics (Thieler et al., 2009).

3.5Present Shoreline Change Analysis

For understanding the long-term shoreline change trend, the study uses the 59 years dataset from 1965 to 2024. Using DSAS, shoreline change analysis were performed with 3452 transects along 71 km.Based on the morphological discontinuity due to geomorphic interruptions the study area was divided into three sectors namely southern sector, central sector and northern sector. For understanding the changes within the sectors, each has been further classified into southern and northern sub-sectors.To quantify the long-term shoreline change, linear regression rate (LRR) was used and to measure the shoreline displacement net shoreline movement (NSM) and shoreline change envelope (SCE) were used. This gives the overall understanding of recent long-term shoreline change trend along the study area.For present shoreline analysis, the focus is the coastal stretch surrounding the Mahanadi River mouth to understand the sediment supply entering the coast and the shoreline response occurs. Specifically, to observe the coastal behaviour such as erosion, accretion, sediment redistribution and spit dynamics around the main sediment source.Along with this, the CORONA 1965 data constraint also plays a role which fails to cover the entire delta belt. Therefore, these differences clearly highlight that the paleo analysis focuses on regional delta evolution whereas the present shoreline analysis focuses on local shoreline behaviour.

Satellite	Sensor	Date of image acquisition	Resolution (m)	Data source
Corona	KH-4A	05-28-1965	2.74	USGS
Corona	KH-9	04-04-1978	6.09	USGS
Landsat	TM	11-29-1990	30	USGS
Landsat	ETM	10-23-2000	30	USGS
Cartosat	Pan	07-07-2006	2.5	NRSA
IRS-P6	LISS-IV	10-21-2012	5.8	NRSA

IRS-P6	LISS-IV	03-14-2013	5.8	NRSA
IRS-P6	LISS-IV	05-20-2014	5.8	NRSA
IRS-P6	LISS-IV	04-21-2015	5.8	NRSA
IRS-P6	LISS-IV	03-22-2016	5.8	NRSA
IRS-P6	LISS-IV	03-17-2017	5.8	NRSA
IRS-P6	LISS-IV	10-23-2018	5.8	NRSA
IRS-P6	LISS-IV	02-11-2019	5.8	NRSA
IRS-P6	LISS-IV	10-21-2021	5.8	NRSA
IRS-P6	LISS-IV	04-08-2024	5.8	NRSA

Table 1 Satellite data used for shoreline extraction and analysis

3.6. DSAS Analysis

Shoreline change analysis was performed using the Digital Shoreline Analysis System (DSAS) in GIS environment (Thieler et al., 2009). Transects were generated at regular intervals to calculate shoreline change statistics.Linear Regression Rate (LRR) was used to quantify the long-term shoreline change using all shoreline positions (Crowell et al., 1991).

$$m = \frac{n\sum xy - \sum x \sum y}{n\sum x^2 - (\sum x)^2}$$

Where m is the slope which address the shoreline change meters per year.

Net shoreline movement (NSM) was used to measure the displacement between the oldest and the most recent shoreline position.

$$NSM = \text{Distance}_{\text{latest shoreline}} - \text{Distance}_{\text{earliest shoreline}}$$

Positive values represent accretion, negative values represent erosion, and zero value indicates no shoreline change.Shoreline change envelope (SCE) are calculated between the maximum extent of the shoreline position. For each transect it represents the greatest distance between the earliest and the most recent shoreline positions to estimate the total shoreline variability between the shoreline analysis period (Thieler et al., 2009; Crowell et al., 1993).

$$SCE = Dmax - Dmin$$

Dmax is a maximum distance from baseline to shoreline along a transect and Dmin is a minimum distance from baseline to shoreline along a transect.

3.7Areal Measurement of Coastal Landforms

Areal measurements were applied to quantify the spatial evolutions of prograded coastal deposits between the paleo and the present shoreline. Using extracted inferred shoreline from map prepared by Geological Survey of India (GSI) and the present shoreline extracted from LISS-IV, spatial areal measurements were extracted in GIS environment.Such areal measurements help to understand the long-term coastal evolution and sediment redistribution along the deltaic coast (Das & Maejima, 1996; Somanna et al., 2016).

4 Results

4.1 Paleo Shoreline Identification and Long-Term Coastal Progradation

For understanding the recent coastal deposits during the Quaternary period, the inferred paleo shoreline was digitized as the transitional boundary between the continental erosional landscape and coastal depositional environment based on the geomorphological map showing coastal origin and geological map showing age prepared by Geological Survey of India (GSI) (Figure 2).The length of the inferred paleo shoreline covers a distance of 157.74 km along the inland parallel to the coast (Figure 3). Based on the morphological discontinuity the study area was divided into three sectors: the southern sector, central sector and northern sector.The southern sector is bounded between tidal inlet at the south and the Mahanadi River mouth at the north. It covers a distance of 54.8 km along inland. To calculate the shoreline displacement using DSAS, transects of around 18 were generated along the 54.8 km cross the inland between the paleo and the present shoreline. The shoreline change envelope results show that the mean shoreline displacement between the paleo and the present shoreline was 79.08 km, and the minimum was 72.18 km and the maximum was 91.56 km (Figure 4, Figure 5). Similarly, the areal measurements of seaward progradation landform show 2565.55 sq km (Figure 4).The central sector is bounded by Mahanadi River mouth at the south and open coast at the north. The central sector covers a distance of 24 km along the inland paleo shoreline. To calculate the shoreline displacement using DSAS, transects of around 11 were generated along the 24 km cross the inland between the paleo and the present shoreline. From the inland inferred paleo shoreline towards the seaward, the shoreline displacement was measured using DSAS. The distance was measured using shoreline change envelope. The measured results show that the mean displaced shoreline distance was 86.98 km from the paleo shoreline towards the present shoreline. The minimum and the maximum distance between the inferred paleo shoreline and the present shoreline reveal 79.77 km and 93.74 km (Figure 4, Figure 5). Whereas the areal measurements indicate that 1550.2 sq km landform has been prograded over the time between the continental erosional landscape and the depositional shoreline environment (Figure 4).The northern sector is bounded by river mouth at the south and bathymetry at the north. It covers a distance of 77.54 km. To calculate the shoreline displacement using DSAS, transects of around 33 were generated along the 77.5 km cross the inland between the paleo and the present shoreline. For the northern sector, the shoreline displaced distance over the time was measured using DSAS. The shoreline change envelope was used to measure the distance between the paleo shoreline and the present shoreline. The result indicates that the mean shoreline displaced distance towards sea was 80.88 km, and the minimum and the maximum shoreline displacement towards sea were 71.3 km and 88.98 km (Figure 4, Figure 5). In this sector the displacement between the paleo and the present shoreline over the time clearly indicates that the shoreline was prograded towards the sea. Similarly, the areal measurement shows 3380.92 sq km because of this prograded landform towards sea (Figure 4).Overall, in all the sectors, paleo shoreline covers a length of 157 km which lies between pediplains and the deltaic older coastal plains (Figure 3). Across sectors, the mean displaced shoreline distance was 80 km over the time from paleo shoreline to the present shoreline, and overall displacement range in all sectors show minimum of 71 km and maximum of 93 km (Figure 5). Across the study area the general pattern shows that the shoreline progradation was towards sea. Similarly, the combined prograded landform area meets 7494.67 sq km (Figure 4). The spatial variation shows that the central sector shows slightly larger displacement compared to southern and northern sectors.

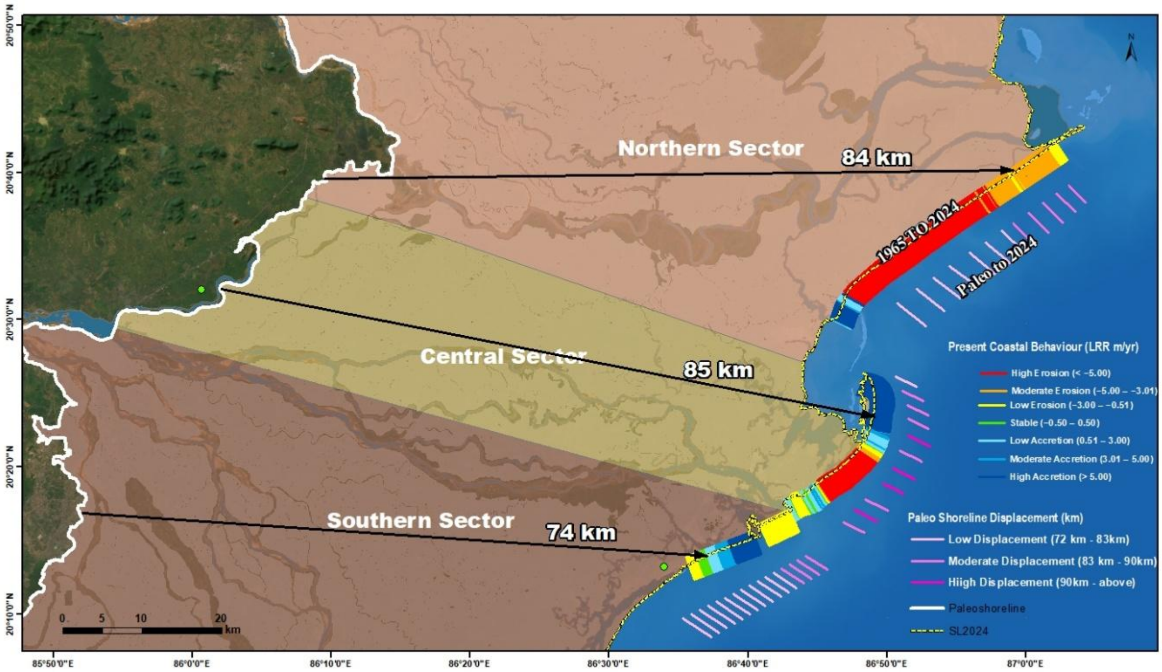

Figure 3 DSAS transects used for paleo displacement and present shoreline change analysis.

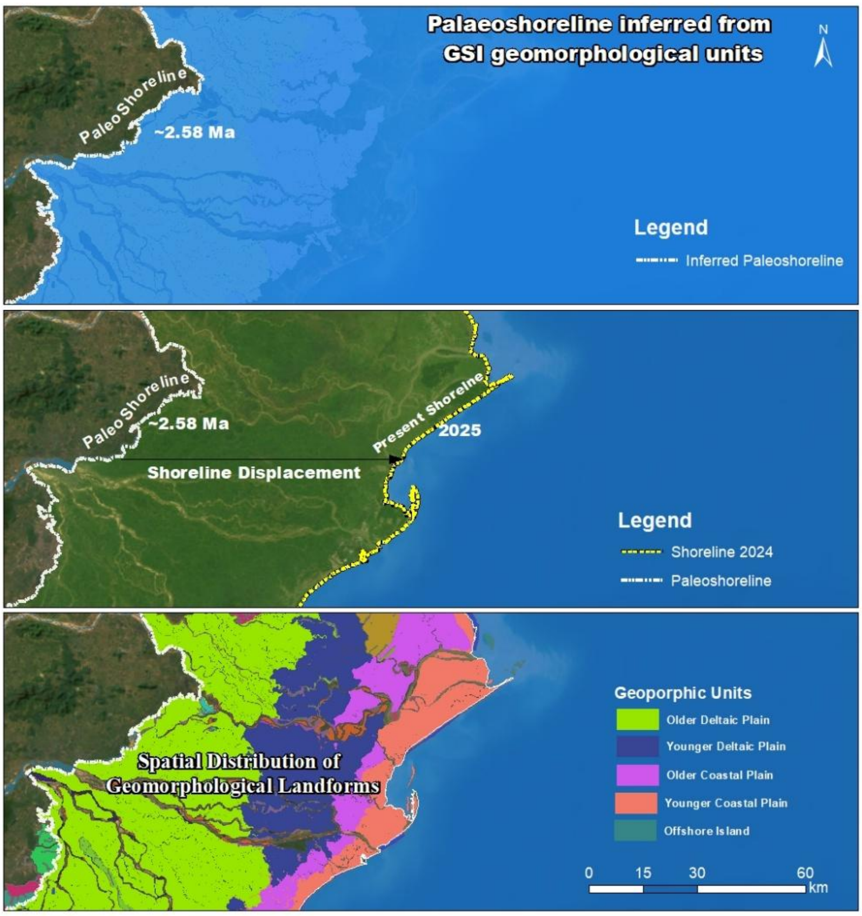

Figure 4Paleo and present shoreline comparison and spatial distribution of landforms.

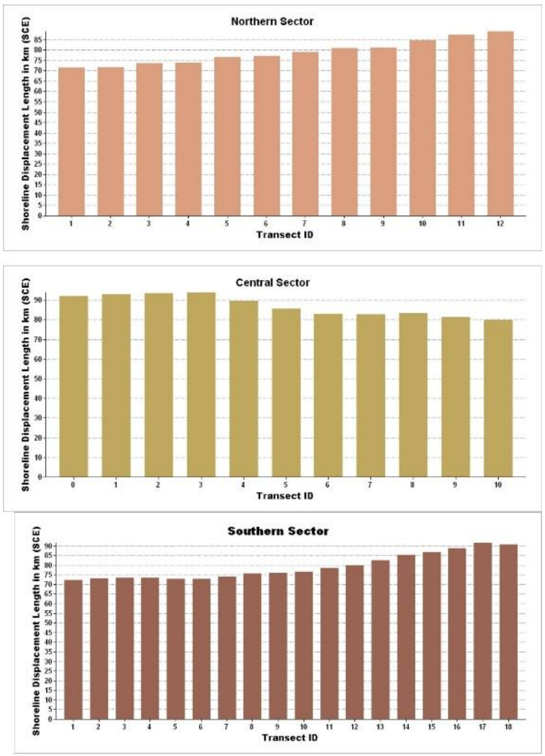

Figure 5 Paleo shoreline displacement across the study sectors.

4.2 Present Shoreline Changes (1965–2024)

For understanding the long-term shoreline change trend, the study uses the 59 years dataset from 1965 to 2024. Using DSAS, shoreline change analysis were performed with 3452 transects along 71 km (Figure 3).Based on the morphological discontinuity due to geomorphic interruptions the study area was segregated into three sectors: the southern, central and the northern sector. For understanding the changes within the sectors, each has been further classified into southern and northern sub-sectors.To quantify the long-term changes LRR is used and to find the long-term shoreline displacement NSM and SCE were used. This gives the overall understanding of recent long-term trend along the study area.In contrast, for understanding the short period which have linked with geomorphic and anthropogenic events and their impacts, short-term analysis was examined based on the post-event period for the specific sector.The shoreline change statistics for the different sectors derived from DSAS were summarised in Table 2.

Sector	Sub-sector	Length (km)	Transects	NSM (m)	SCE (m)	LRR (m/yr)	Dominant trend
Southern	Southern	8.9	448	209.62	300.75	3.41 ± 0.36	Accretion

	Northern	4.1	206	-124.14	149.3	-1.15 ± 0.48	Erosion
Central	Southern	7.5	278	-91.01	145.37	-3.47 ± 1.14	Erosion
	Northern	14.4	715	517.59	523.34	25.34 ± 5.28	Accretion
Northern	Southern	32.8	1627	256.34	433.37	6.29 ± 0.58	Accretion
	Northern	3.8	178	-482.94	484.68	-7.91 ± 0.22	Erosion

Table 2. Shoreline change statistics derived from DSAS analysis.

4.2.1 Southern Sector Shoreline Changes

The southern sector is bounded by tidal inlet at the south and river mouth at the north. It covers a distance of 13.1 km which is divided into sub-sectors such as southern sub-sector covers a distance of 8.9 km and the northern sub-sector covers a distance of 4.1 km.Using LRR, the long-term trend over the 59 years indicates the accretional trend of 3.41 ± 0.36 m/yr (Figure 6).Whereas net shoreline change and shoreline change envelope show the shoreline displacement of 209.62 m and 300.75 m over the years. This evidence clearly indicates that southern sub-sector is dominated by the accreting trend.In contrast, at the northern sub-sector the results of linear regression rate show the long-term eroding trend of -1.15 ± 0.48 m/yr (Figure 6).Similarly, the net shoreline movement and shoreline change envelope show the landward shift of -124.1 m and 149.3 m. All these results reflect the same eroding trend, where shoreline has moved landward.

4.2.2 Central Sector Shoreline Changes

The central sector is bounded between river mouth at the south and geomorphic break at the north. It covers a distance of 21.9 km, which is divided into southern and northern sub-sectors.

The sub-sectors were divided based on the spit alignment during the year 2000. At the point of alignment the sub-sectors are divided into southern and northern sub-sectors.The southern sub-sector covers a distance of 7.5 km.Using the 279 transects generated by DSAS, the shoreline changes were analysed. From the results, the long-term regression rate shows -3.47 ± 1.14 m/yr (Figure 6).Similarly, the NSM and SCE also show the eroding shoreline displacement of -91 m and 145.37 m. All these evidences clearly indicate that the southern sub-sector was under eroding trend over the period.In contrast, northern sub-sector shows continuous accreting trend. The northern sub-sector covers a distance of 14.4 km, which is the largest distance compared to southern sub-sector.The long-term results of linear regression rate show 25.34 ± 5.28 m/yr (Figure 6). During the period, the NSM and SCE show the drastic shoreline displacement of 517 m and 523.34 m.Across the whole sector, the accretion was dominated along this sub-sector.

4.2.3 Northern Sector Shoreline Changes

The northern sector is bounded by the river mouth at the south and geomorphic break at the north. It covers a distance of 36.6 km.Based on the erosion and accretion transition point, this sector was further classified into southern and northern sub-sectors.The southern sub-sector covers a distance of 3.8 km, whereas the northern sub-sector covers a distance of 32.8 km.Along this stretch the long-term result of LRR shows the accreting rate of 6.29 ± 0.58 m/yr (Figure 6).Along this stretch the NSM and SCE of shoreline displacement show the accreting trend of 256.3 m and 433.37 m. This clearly indicates that the coast was continuously prograding over the period. Whereas the northern sub-sector shows the long-term trend of -7.91 ± 0.22 m/yr. Similarly, the NSM and SCE also show the eroding shoreline displacement of -482.94 m and -484.68 m over the 59 years. All these evidences clearly indicate that the coast was continuously eroding for long period. The alongshore variation of present shoreline changes along the coast is shown in Figure 6.

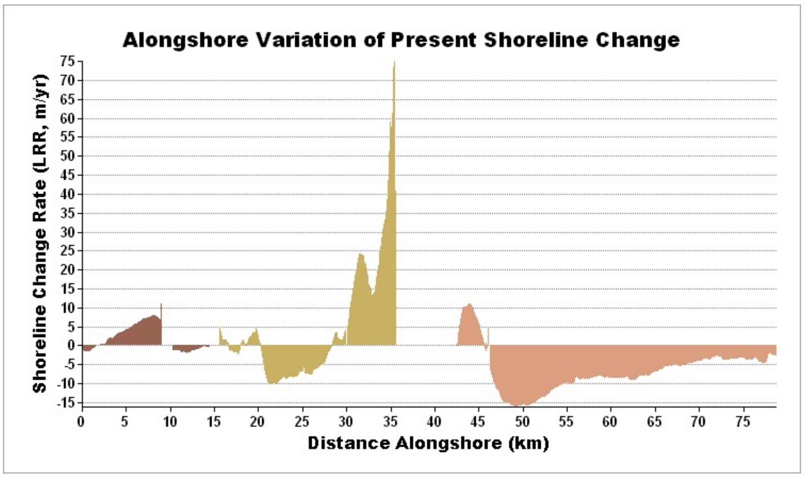

Figure 6 Paleo shoreline displacement across the study sectors.

5 Discussion

5.1 Significance of the Inferred Paleo Shoreline

To demarcate the paleo shoreline, boundary between the pediplains with alluvial plains and deltaic coastal plains was marked as an inferred paleo shoreline (Bloom, 2003; Summerfield, 1991). The pediplain was considered as a continental erosional landform which address the continental terrain whereas the deltaic plains were considered as a fluvial and coastal depositional region by Mahanadi River (Bloom, 2003). So, in light of this transitional geomorphic between the pediplain and the coastal depositional area, the former inland limit of deltaic sedimentation is interpreted as the inferred paleo shoreline (Somanna et al., 2016).

5.2 Long-Term Delta Progradation and Coastal Evolution

Over the long period, the paleo shoreline has been displaced up to 80 km towards sea (Galloway, 1975; Wright & Coleman, 1973; Somanna et al., 2016). Similarly, between the displaced shoreline of inferred paleo shoreline and present shoreline (2024), 7494.7 sq km of landform was prograded towards sea.Over the years, behind this huge landform and displaced shoreline towards sea, river plays a major role in bringing the huge volume of sediment from the continental inland and deposited in the fluvial and coastal sedimentation region (Wright &Coleman, 1973; Bastia &Equeenuddin, 2016). Further this was reworked by the coastal process agents such as tide, waves and currents (Komar, 1998; Masselink et al., 2011).So continuous supply of sediment from the river and continuous rework by the coastal process together make an inferred paleo shoreline to march seaward (Bird, 2008).

5.3 Sector-Wise Modern Shoreline Behaviour

Over the 59 years, the result shows that southern sector is dominated by the accretion with local erosion. The central sector is redistributed between erosion and accretion and the northern sector is dominated by the continuous erosion.Across the sector the pattern explains that the southern sector show accretion at the southern side and erosion at the northern side.

5.4 Influence of Sediment Supply and Anthropogenic Structures

At the southern sector where accretion dominated at the south and erosion dominated at the north was patterned due to the impact of port breakwater which was constructed in 1965 (Dean & Dalrymple, 2002).Due to the presence of the breakwater the southern part breakwater traps the sediment and accumulated the sediment which was brought by the littoral southern currents (Komar, 1998). Since the sediment could not bypass the breakwater, the sediment was locally accumulated andcause erosion at the north. So due to the anthropogenic impact the southern side of the port is accreting and the north is eroding.In the central sector the reverse pattern was observed which show southern side show continuous erosion and the northern side was continuously accreting. This is purely based on the insight that absence of adequate river sediment supply from the river point source (Bastia &Equeenuddin, 2016). This impact trap the sediment locally along the southern side and cause erosion and the eroded material are deposited at the north distal portion of the spit (Masselink et al., 2011). This result in the huge accretion at the north.The northern sector is continuously eroding due to the absence of adequate supply of sediment which makes to trap the sediment locally and cause erosion along the coast (Bird, 2008). But noticeably small portion of the sector, southern sub-sector shows continuously accreting. This may due to the reverse current, northern reverse current may feed the southern coast and hence the northern sector is patterned by accretion at the south and erosion at the north.The overall behaviour of the modern sectors clearly shows that the coast is not continuously receiving the sediment from river source which results in localized erosion and accretion and hence it is not uniformly prograding in recent years compared to past delta progradation (Bastia &Equeenuddin, 2016; Galloway, 1975) (Table 3).

Sector	Long-term Trend	Recent Trend	Coastal Behaviour
Southern	Progradation	Accretion	Accreting
Central	Moderate progradation	Erosion	Eroding
Northern	Strong progradation	Erosion	Eroding

Table 3. Integrated coastal evolution across the study sectors.

6 Conclusion

The inferred paleo shoreline was delineated between the geomorphic transitions of pediplain / alluvial plains and deltaic coastal plains for comparing with the present shoreline. And the long-term coastal evolution highlights that from the former paleo shoreline position, present shoreline position has been displaced 80 km towards sea which indicates the large-scale delta growth.From the earlier shoreline condition clearly indicates that the delta has been continuously prograding due to the continuous supply of sediment from the Mahanadi River. But the present coast, shoreline results indicate that the southern sector was continuously accreting with local erosion due to anthropogenic impact, central sector behaviour indicates the redistribution of sediment from south to north, and northern sector was continuously eroding, all indicates the lack of adequate sediment supply to the coast. And this coastal instability may influence the ecologically important habitats. All these evidences clearly indicates that modern shoreline behaviour and its evolution are controlled by the lack of adequate sediment supply from the rivers and the anthropogenic structure impacts, so it is not uniformly prograding like past delta progradation.

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