Geospatial techniques to determine Coastal geomorphology changes along the Cuddalore and Nagapattinam coast, Tamil Nadu, India

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Abstract
This study proposes to use geospatial techniques to assess coastal geomorphological changes along the southeast coast of India, from Cuddalore to Nagapattinam. The results will provide insights into regional morphology changes and will advance our understanding of coastal evolution, sea level variations and quaternary geomorphic processes. The coastal geomorphological units of the study area comprise of the coastal zone and an older deltaic plain.

Most coastal zone features have developed through erosion, accretion and other natural processes. These features can be classified as depositional or erosional. By analyzing satellite imagery from 1980 to 2020, the study identified changes in coastal geomorphological features. This information can be used to locate mineral deposits, hydrocarbon locales, groundwater targets and sites for artificial recharge and saltwater intrusion mitigation. It can also affect coastal zone management decisions.

Keywords: Satellite imagery, coastal geomorphology, depositional, erosional, GIS.

Introduction

Information about climate change impacts at local and regional scales is essential for developing adaptation strategies and motivating mitigation efforts[2,8,14,19,23]. Understanding the impacts of climate change on Earth systems is crucial, given the implications for food production, water resources, ecosystem services, physical infrastructure and land carbon sinks[6,10,22]. The coastal zone is one of the most delicate, complex and economically valuable biological systems. Coastal geomorphology is increasingly being used to study the relationship between coastal ecosystems and climate change.

As the effects of climate change on the coast are often viewed in terms of geomorphological adjustment to sea level rise, geologists are beginning to unravel the nuances of how coastal processes are forced by broader climatic factors[7,9,16]. Coastal geomorphology is highly sensitive to climate change due to the strong correlation between atmospheric warming and sea level rise and the primary role of the latter in determining the boundaries of tidal and intertidal landforms. The different geomorphic landforms created during the quaternary period bear the imprints of past geological events and this region's fluvial processes can be used to trace paleo-river courses, river pattern migration and the inherent relationship between sea level oscillations and channel shifting.

In India, quaternary studies gained new impetus in the early 1980s with the advent of aerial photography and remote sensing techniques that improved precision. In the study area[17], evidence of the emergence of the southern Tamil Nadu coast has been found including the presence of abandoned channels and a crustal flexure caused by cymatogenic downwarping along the northern coast of Tamil Nadu1. Heavy minerals have been identified in various Quaternary landforms[15,24] and coastal geomorphology has been studied in the Portonova region. Quaternary sea level changes (glacial and interglacial periods) have resulted in shoreline translocation along the Coromandel coast of India[11,12,18,27].

These coastal regions face severe impacts from both anthropogenic and natural factors such as shoreline and coastal erosion, sea level variation and major cyclones every monsoon season[7,13]. Coastal regions are constantly changing in shape and environment due to natural processes and human interventions[26]. Coastal transformation has become a matter of great concern in recent years and the measurement of coastlines is an important factor in coastal zone management.

Coastal geomorphology can inform afforestation efforts in the coastal region using mangroves[5]. The study region has transitional fluvial and marine landforms. The coastal area is developed on sedimentary formations and is vulnerable to destruction by wave action. Coastal geomorphology can help to afforest the coastal region and create protective structures against wave action and coastal erosion[3].

Study area

The study area extends from 11°77′N 79°69′E to 10°74′N 79°92′E. It is bound by the Ponnaiyar river basin to the north and the Uppanar river basin to the south. The study area stretches from Cuddalore New Town in the west to Nagapattinam in the east. It covers the districts of Cuddalore, Sirkazhi, Chidambaram, Thiruvarur, Tharangambadi and Nagapattinam as well as part of the Karaikal district in the state of Pondicherry. The study region is well connected by roads and railways.

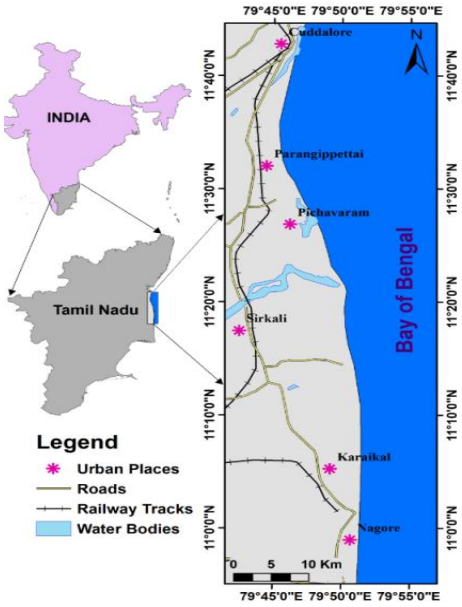

Figure 1: Location map of the Study area

Material and Methods

This study utilized Survey of India (SOI) toposheets and satellite images which were visually interpreted and field-verified. The methodology involved three main steps: Satellite data from Landsat ETM+ (Enhanced Thematic Mapper Plus), MSS (Multispectral Scanner), TM (Thematic Mapper) and IRS-P6 LISS III (Indian Remote Sensing-P6 Linear Imaging Self Scanner-III) which were used to identify the coastal geomorphology conditions in the study area. Arc GIS 10.2 software was used to evaluate coastal geomorphology and analyze changes. Different types of landforms and associated structural features were mapped from satellite data. This methodology resulted in a coastal geomorphology map from reliable satellite data which was used to obtain accurate results. The features delineated in the maps were checked, modified and corrected during field work[20,23].

Coastal geomorphology mapping

The study region is mostly covered by the Cauvery delta and flanked by the Ponnaiyar, Gadilam and Uppanar river systems to the south and the Vellar, Coleroon, Arasalar, Tirumalarajanar and Vettar river systems to the north. The coastal zone comprises a variety of fluvial, fluvio-marine and marine landforms. The following coastal geomorphic features were interpreted from the digitally processed satellite data: Cuddalore sandstone upland, floodplain, sandbar, point bar, river island, rivers and streams, delta plain, paleo-beach ridges, paleo-swales, paleo-lagoonal plains, swales, lagoons, mangrove swamps, mudflats and salt pans, beach ridges and beach and bay mouth bars and spits. These features are generally found throughout the study region, although some positive features such as clear drainage systems and rivers, were more prominent in certain areas.

Results and Discussion

The Cuddalore-Nagapattinam coastal area is a region characterized by a rich diversity of geomorphic features, each with its own distinct configuration and evolution over the years. These landforms have been identified through the interpretation of satellite imagery from various years and validated through field observations, culminating in the categorization of 17 distinct classes. Bay Mouth Bars and Spits, which often act as natural barriers between the open ocean and coastal water bodies, have experienced a reduction in extent over the years due to factors such as flooding and tsunamis.

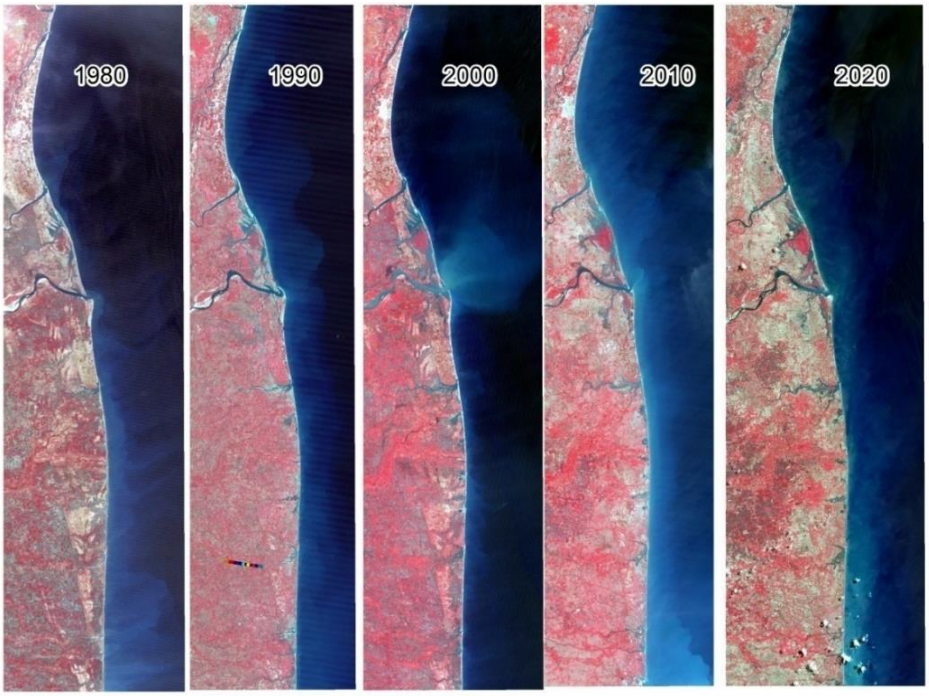

Figure 2: False Colour Composite Maps (Green, Red and Infrared)

Table 1
Geomorphic changes in the Cuddalore to Nagapattinam coastal area between 1980-2020

Geomorphic feature	Area in 1980 (sq km)	Area in 2020 (sq km)	Change
Bay mouth bars/spits	8.24	3.47	Decreased by 58%
Beach ridges	263.41	261.88	Decreased by 0.6%
Beaches	23.48	12.45	Decreased by 47%
Cuddalore sandstone upland	41.62	30.62	Decreased by 26%
Deltaic plain	600.1	562.15	Decreased by 6.3%
Floodplain	73.73	332.86	Increased by 352%
Lagoon	2.13	0.65	Decreased by 70%
Mangrove swamps	7.2	6.99	Decreased by 3%
Mudflats/salt pans	53.61	77.29	Increased by 44%
Paleo-beach ridges	163.54	58.62	Decreased by 65%
Paleo-lagoonal plains	16.39	5.11	Decreased by 69%
Paleo-swales	20.85	14.82	Decreased by 29%
Point bars	13.84	4.75	Decreased by 62%
River islands	3.82	6.66	Increased by 74%
Rivers/streams	46.32	9.43	Decreased by 79%
Sand bars	0.42	9.43	Increased by 2236%
Swales	256.78	152.47	Decreased by 41%

Table 2
Statistics of the Coastal Geomorphology in the study area1980 to 2020 (in sq.km)

Coastal Geomorphology	1980 (sq.km)	1980 (%)	1990 (sq.km)	1990 (%)	2000 (sq.km)	2000 (%)	2010 (sq.km)	2010 (%)	2020 (sq.km)	2020 (%)
Bay Mouth Bars / Spits	2.34	0.15	2.21	0.14	0.9	0.06	1.71	0.11	1.78	0.11
Beach Ridges	263.41	16.57	257.95	16.31	197.45	12.38	94.78	5.99	261.88	16.5
Beaches	23.48	1.48	18.98	1.2	21.26	1.33	11.56	0.73	12.45	0.78
Cuddalore sandstone upland	41.62	2.62	38.13	2.41	36.15	2.27	32.46	2.05	30.62	1.93
Deltaic plain	600.1	37.75	517.07	32.7	398.94	25.01	768.05	48.5	562.15	35.41
Flood plain	73.73	4.64	224.19	14.18	515.08	32.3	135.68	8.57	332.86	20.97
Lagoon	2.13	0.13	2.12	0.13	0.46	0.03	0.28	0.02	0.65	0.04
Mangrove Swamps	7.2	0.45	6.75	0.43	8.01	0.5	11.07	0.7	6.99	0.44
Mudflats / Salt Pans	53.61	3.37	57.73	3.65	46.42	2.91	67.65	4.27	77.29	4.87
Paleo - Beach Ridges	163.54	10.29	170.45	10.78	63.85	4	185.62	11.72	58.62	3.69
Paleo - Lagoonal plains	16.39	1.03	3.76	0.24	3.97	0.25	4.05	0.26	5.11	0.32
Paleo Swales	20.85	1.31	28.43	1.8	23.97	1.5	34.26	2.16	14.82	0.93
Point Bar	13.84	0.87	1.94	0.12	0.56	0.04	1.79	0.11	4.75	0.3
River Island	3.82	0.24	3.82	0.24	4	0.25	3.85	0.24	6.66	0.42
Rivers / Streams	46.32	2.91	55.09	3.48	72.24	4.53	45.3	2.86	48.93	3.08
Sand bar	0.42	0.03	0.56	0.04	4.32	0.27	5.29	0.33	9.43	0.59
Swales	256.78	16.15	192.23	12.16	197.23	12.37	11.37	11.37	152.47	9.6

Notable occurrences are found at the mouths of the Coleroon, Vellar, Uppanar and Gadilam rivers. The area covered by beach ridges has also decreased, indicating changes in the coastal landscape. Beaches, in particular, have seen a reduction in area, likely due to the dynamic nature of these landforms, influenced by wave action and longshore currents. Cuddalore Sandstone Upland diminished in size, partly as a result of human activities such as laterite removal, which has made it more susceptible to erosion and the development of gullies and badland features.

The deltaic plain, dominated by fertile alluvial soil, covers a substantial part of the study area. It has witnessed fluctuations in its extent over time, likely influenced by factors such as sediment deposition from the Cauvery River and its distributaries.

The floodplain has increased in area, largely attributed to natural disasters like floods and tsunamis that have affected the eastern coast of Tamil Nadu. This expansion can be connected to the landward shifting of the flood line. Lagoons

are shallow bodies of seawater separated from the open sea by narrow landforms. In this region, Pitchavaram lagoon is a prominent example. Lagoon areas have seen a decrease in recent years with controlled tidal inlets playing a role. Mangrove swamps have been impacted by natural events like the 2004 tsunami and anthropogenic activities including agriculture and aquaculture. Their extent has diminished as a result.

The mudflats and salt pans along various rivers and water bodies have seen an increase in area likely influenced by the development of mudflats during transgressions, high tides and storm seasons. Paleo-Beach ridges have experienced a decrease in extent over time, likely influenced by various geomorphic processes.

Paleo-Lagoonal Plains: Similarly, the paleo-lagoonal plains have seen a decrease in area. Paleo-Swales features have also experienced a reduction in extent over the years. Point bars, associated with river meandering, have seen a decrease in area. River islands have increased in extent, possibly due to the influence of events like the 2004 tsunami and seasonal variations. The area covered by rivers and streams has increased influenced by the shifting of the Tamil Nadu coast geomorphology due to events like 2004 tsunami.

Table 3
Statistics of the Coastal Geomorphology diffrences in the study area from1980 to 2020 (in %)

Coastal Geomorpology	Year 1980 (Area in %)	Year 2020 (Area in %)	1980 to 2020 changes in %
Bay Mouth Bars / Spits	0.15	0.11	-0.04
Beach Ridges	16.57	16.5	-0.07
Beaches	1.48	0.78	-0.7
Cuddalore sandstone upland	2.62	1.93	-0.69
Deltaic plain	37.75	35.41	-2.34
Flood plain	4.64	20.97	16.33
Lagoon	0.13	0.04	-0.09
Mangrove Swamps	0.45	0.44	-0.01
Mudflats / Salt Pans	3.37	4.87	1.5
Paleo - Beach Ridges	10.29	3.69	-6.6
Paleo - Lagoonal plains	1.03	0.32	-0.71
Paleo Swales	1.31	0.93	-0.38
Point Bar	0.87	0.3	-0.57
River Island	0.24	0.42	0.18
Rivers / Streams	2.91	3.08	0.17
Sand bar	0.03	0.59	0.56
Swales	16.15	9.6	-6.55

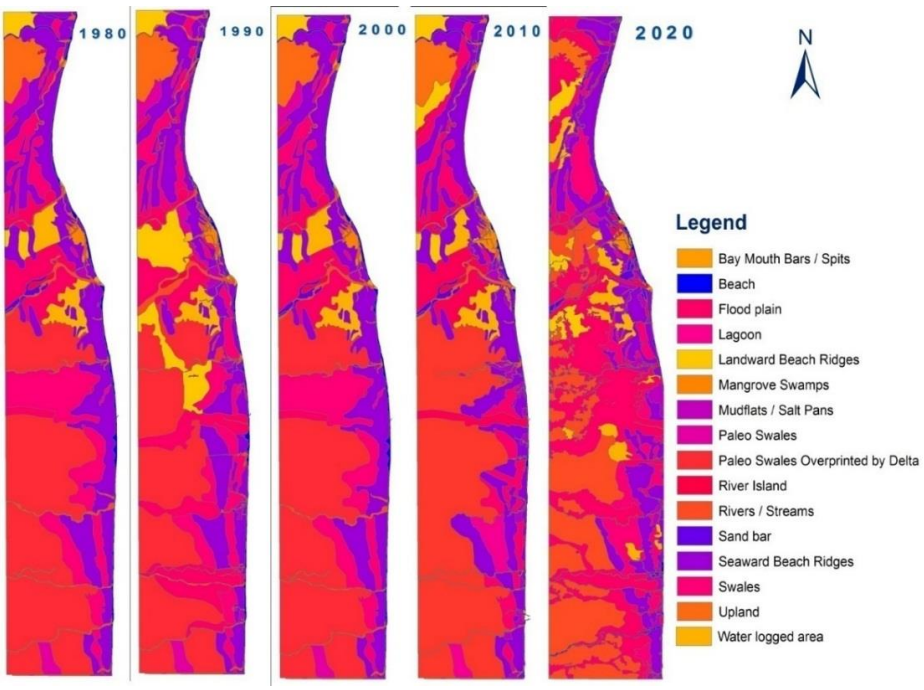

Figure 3: Map showing the Coastal Geomorphology in the year 1980 to 2020

Sand bars, linear landforms formed by the deposition of granular material, have seen an increase in area. Swales, which are depressions or low-lying areas, have experienced a decrease in extent. The geomorphic features of the Cuddalore-Nagapattinam coastal area have evolved over the years, influenced by both natural events and human activities. These changes have implications for the region's ecology, agriculture and overall coastal dynamics. The study provides valuable insights into the dynamic nature of coastal landscapes and the need for sustainable management and conservation practices in the face of ongoing environmental changes (Figs. 4a and b).

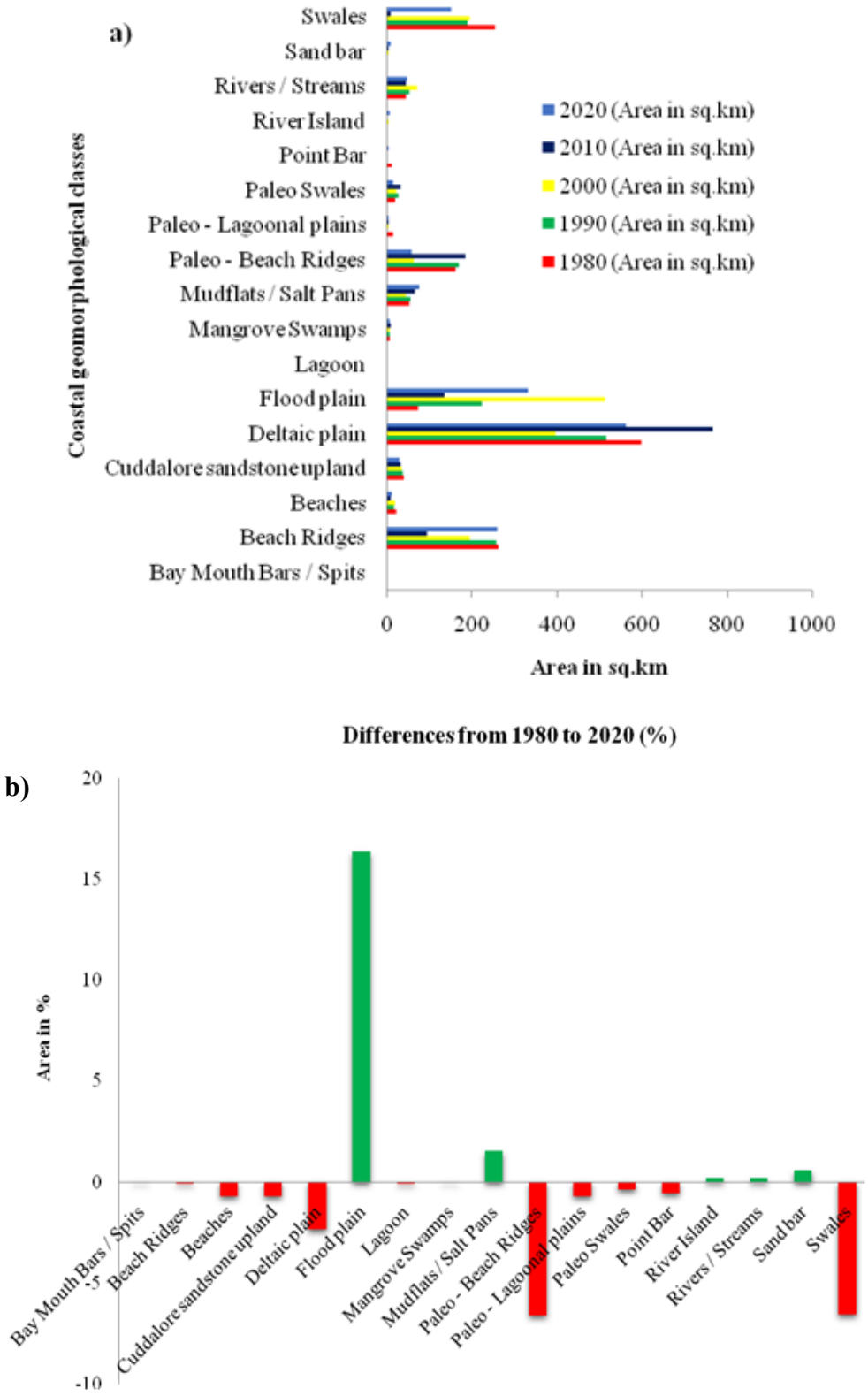

Figure 4: Coastal Geomorphology changes (1980 to 2020): a) in sq.km; and b) in percentage

Conclusion

The coastal geomorphic studies can improve and protect the coastal zone in vulnerable areas. The present study has brought out recent and full information on the vulnerability of coastal regions, coastal geomorphology, land use and land cover and shoreline changes over several years (1980–2020). The coastal rural community and coastal population are affected by the projected accelerated sea level rise in the Nagapattinam region. The coastal geology has been controlled by tidal effects and winds. The tectonic uplift will cause abrupt changes in the river's direction. Transgression and regression caused drastic changes in the sea due to various effects, like sea level changes due to tectonic movement. Major changes in the sea that happened for increasing and decreasing beach ridges were due to the impact of the tsunami that appeared in 2004. The areas near the shoreline might have quick access to vulnerable zones, but in the case of human settlements near the shoreline, they cause loss of life and property.

In 2004, a tsunami caused drastic changes in the shoreline such as changes in soil profile, coastal morphology and land use and land cover in the study area. In fact, there are negative factors such as increased wasteland and reduced mangrove forest. Immediate attention is required towards the increase of mangrove forest because it has to be a natural protection against natural calamities. According to the result, these coastal areas suffered from different factors and this impact can be reduced by defending the coastal area with green shielding. According to this research, both coastal geomorphology and coastal resources are suitable areas for bioshielding.

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