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Assessing Environmental Impact of Shoreline Changes Along the Odisha Coast Using DSAS and Satellite Imagery – A Study of Erosion and Accretion Patterns

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Abstract: A shoreline is nothing but a line interface existing between land and water known as shoreline. In this paper, the study has been conducted along the Odisha coast, India. The coastal districts in Odisha are Baleswar, Bhadrak, Ganjam, Jagatsinghpur, Kendrapara and Puri. In the present study, we calculate the shoreline changes in Odisha coast with help of USGS Earth Explorer satellite images of 1990, 2000, 2010, 2022. The Digital Shoreline Analysis System (DSAS) has been utilised to compute the rates of shoreline erosion and accretion. The End Point Rate (EPR) and Linear Regression Rate (LRR) techniques have been estimated to quantify the rates of coastal changes. In Odisha coastal districts, the area length is Ganjam (60.85 km), Puri (136.48 km), Jagatsinghpur (58.95 km), Kendrapara (83.55 km), Bhadrak (52.61 km), Baleshwar (87.96 km) and total area of Odisha coast is 480.40 km. The current study suggests that in order to remove the risk, adequate beach filling and projects should be implemented in the studied region. The erosion and accretion of coastal regions are caused by both natural and man-made processes, as well as event impacts. The study might be used to more sophisticated planning and development as well as the decision-making procedures utilised by natural disaster management authorities in the studied region.

Key words: Odisha coast, USGS Earth Explorer, DSAS software, erosion and accretion.

Introduction

The shoreline is very important for human beings and sea living things. It is continuously affected by sea level alternative, climate changes and ecosystems that occur over a wide range of timelines, from geological time to short or large disasters like as storms, waves, wind and natural driving forces that effortlessly move the unconsolidated soil and sand particles in the coastal zone, results are dynamically varying in the position of the coastline. The coastline changes are caused by natural or manmade forces such as wind, waves, and disasters that move the sand. The three different types of changes are episodic, long-term, and short-term. Shoreline movement is also influenced by changes in sea level. Long-term change lasts several years, whereas episodic change happens in reaction to a single storm. The short-term change indicates the movement that lasts for several seasons. The term “shoreline” is defined as the dynamic boundary where terrestrial land meets the aquatic environment, influenced by various factors, including tidal fluctuations, wave action, and human activities. This definition emphasises the complexity of shorelines as they are not static; they are subject to continuous change due to both natural processes, such as sediment transport and erosion, and anthropogenic influences, including coastal development and land use changes.

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To provide clarity, the study also includes definitions of related key concepts. For instance, "erosion" refers to the process through which materials from the shoreline are worn away and removed by natural forces, such as waves, currents, and tides. This process can lead to the loss of land and impact coastal ecosystems. In contrast, "accretion" describes the gradual buildup of sediment along the shoreline, resulting in land formation and the expansion of terrestrial areas into aquatic zones.

By explicitly defining these concepts, the study aims to enhance the understanding of shoreline dynamics and the processes at play in the context of erosion and accretion patterns along the Odisha coast. This clarity is crucial for interpreting the findings accurately and assessing their implications for environmental management and policy development.

Shoreline dynamics are driven by a combination of natural processes and human activities, resulting in continuous changes along coastal environments. Erosion and accretion, influenced by factors such as wave action, tides, storm surges, and sea-level rise, are key components of shoreline change (Bird, 2008). Human interventions, including coastal infrastructure development, dredging, and the construction of seawalls, further accelerate or mitigate these changes (Ashton & Murray, 2006). Effective coastal management strategies require understanding these dynamics and integrating both engineering solutions, such as beach nourishment and seawalls, and ecosystem-based approaches like the restoration of mangroves and dunes to promote sustainable shoreline protection (Douvere, 2008).

The 480 km long shoreline of Odisha, which stretches from the Ganjam coast in the south to the Balasore coast in the northern context, is described in the research area by Kar et al. (2021). The study's goal is to complete the data gaps left by past research in order to analyse shoreline change throughout the whole coast of Odisha at various geographical and temporal scales.

The Coastal Belt of the Visakhapatnam District was chosen as the research location.

Hence several researches were carried out to analyse the shoreline changes across varied locations on the Earth using geospatial technology (Venkatesan et al., 2016a, 2020c, 2023).

Need for Study

The coast is a vital and significant region. It cleans stormwater runoff before it enters the river and offers fish and wildlife a rich, dynamic environment. Shoreline or coastline plays a major role geologically and ecologically in filtering pollutants (Karunanidhi et al., 2021; Sivakumar et al., 2014; Suleyman et al., 2004; Venkatesan et al., 2012; Venkatesan and Subramani 2016) and providing domain areas for fishes and other sea organisms.

To protect the shoreline is most important to prevent erosion and accretion. The shoreline gives the water's edge structural integrity, preventing erosion.

Study Area

Odisha coast as shown in Figure 1 is selected for this study; Odisha was once known as Orissa. One of the States of India is called Odisha. It is situated between the meridian of 81.27' E and 87.29' E longitudes and the parallels of 17.49' N and 22.34' N latitudes. The coast is bordered by Madhya Pradesh borders on the west, Bay of Bengal borders on the east and Andhra Pradesh borders on the south.

The coastline of Odisha, which covers 155,707 square kilometres, is around 450 miles long. Odisha coastal consists of the districts of Baleswar coastal length is 87.96 km, Bhadrak coastal length is 52.61 km, Ganjam coastal length is 60.85 km, Jagatsinghpur costal length is 58.95 km, Kendrapara coastal length is 83.55 km and Puri coastal length is 136.48 km.

Satellite Data

Satellite data or satellite imaging refers to the data that artificial satellites in orbit collect data about Earth and other planets in space. Earth observation (EO) satellites provide data on the Earth's surface and weather forecasts, making this use of satellite data the most popular. The satellite data are collected in USGS Earth Explorer software for analysis of the Shoreline Change in Odisha coast in 1990, 2000, 2010, and 2020 years. The satellite data collected is as shown in (Table 1).

Table 1: Satellite data collected for the study

S.No	*Date of accquisition*	*Satellite/Sensors*	*Resolution*	*Spectral band*	*Wrs path/Row*
1	1990/04/11	LANDSAT 5/TM	30	7	139 / 045
2	2000/03/29	LANDSAT 7/ETM	30	8	139 / 045
3	2010/01/28	LANDSAT 5/TM	30	7	139 / 045
4	2022/03/10	LANDSAT 9/OLI_TIRS	30	9	139 / 045

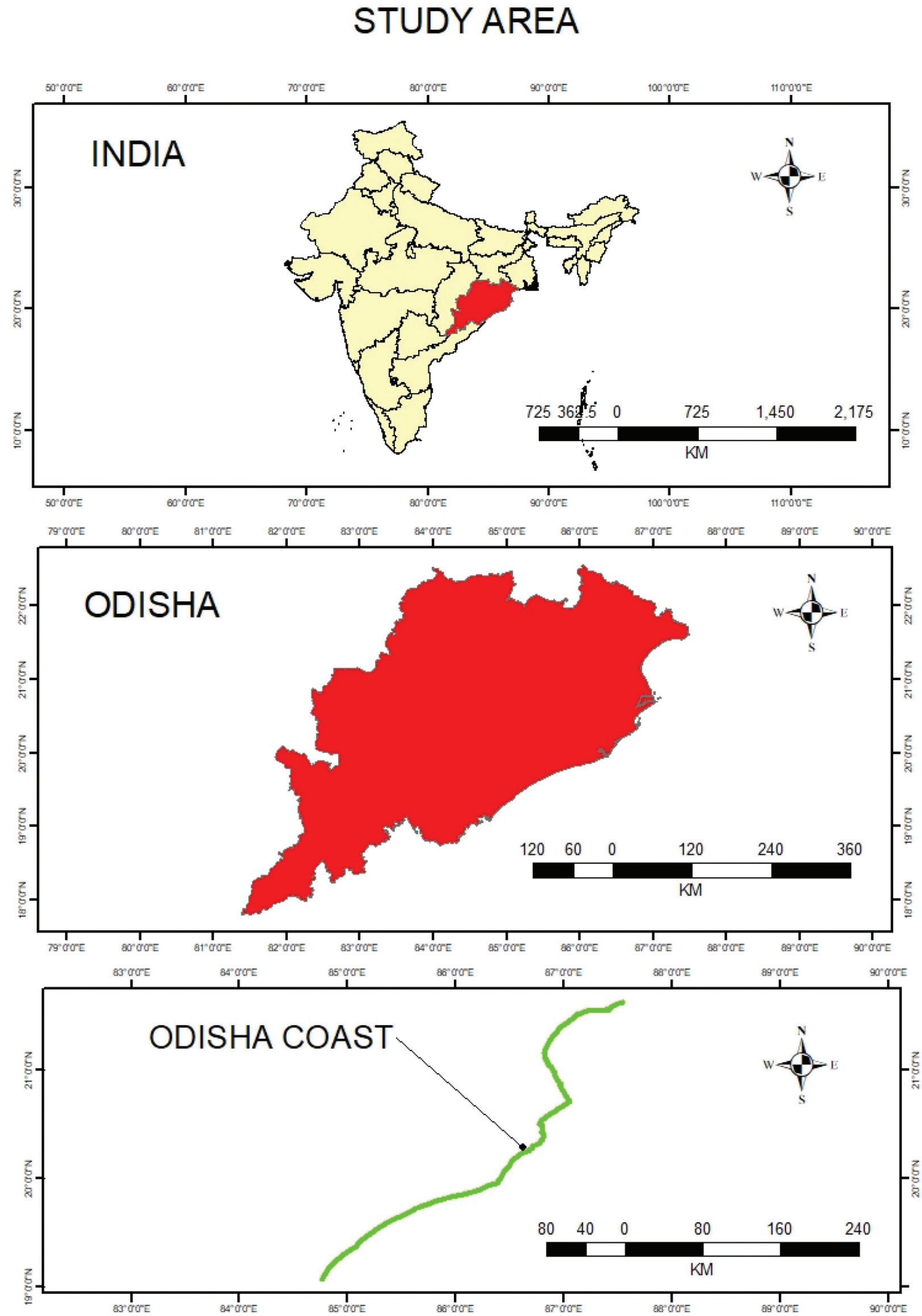

Figure 1: Visual representation of the study area.

Methodology

A methodology has been followed as shown in Figure 2 in order to research the shoreline alterations analysis along the Odisha coastal shoreline tract. By digitising satellite photos from various time periods and converting them into shapefiles, shorelines from the many satellite images 1990, 2000, 2010, and 2022 are retrieved.

The methodology for using the Digital Shoreline Analysis System (DSAS) incorporates the Endpoint Rate (EPR) and Linear Regression Rate (LRR) techniques, which are essential for accurately assessing shoreline changes. The DSAS framework enables a detailed analysis of historical shoreline positions, facilitating the quantification of erosion and accretion rates over time (Thieler et al., 2009). The EPR technique is particularly useful for providing straightforward estimates of shoreline change based on the distance between endpoints of transects, while the LRR method offers a statistical approach to evaluate trends and rates of change across multiple observations (Crowell et al., 1997).

This study not only addresses the physical aspects of shoreline changes but also explores their ecological and economic implications. Understanding erosion and accretion rates is vital for coastal management, as these changes can significantly impact local ecosystems, habitats, and community livelihoods (Nordstrom, 2000). Therefore, a comprehensive analysis that integrates both environmental and socio-economic factors is crucial for developing effective strategies for shoreline management and conservation (Klein et al., 2001).

To enhance clarity and facilitate interpretation, the presentation of transect data adheres to a standardised format throughout the manuscript. This consistency aids in understanding the patterns of shoreline change and provides a clearer visual representation of the findings (Boak & Turner, 2005). By presenting the data in a coherent manner, the study aims to enhance the reader's ability to grasp the complexities of shoreline dynamics along the Odisha coast.

Extraction of Shoreline

Through the online visual digitisation of the vector data from USGS Earth Explorer, the coastline analysis utilising various temporal satellite photos is recovered. Each satellite picture was manually digitised one by one to extract the coastline. Digitised shorelines are displayed in Figure 3.

After completing the digitisation of shoreline by using ArcGIS next create personal geodatabase for analysis of the shoreline data, in personal geodatabase to create two feature class data for shoreline and baseline to run transect in DSAS tool. As a next step, transects were

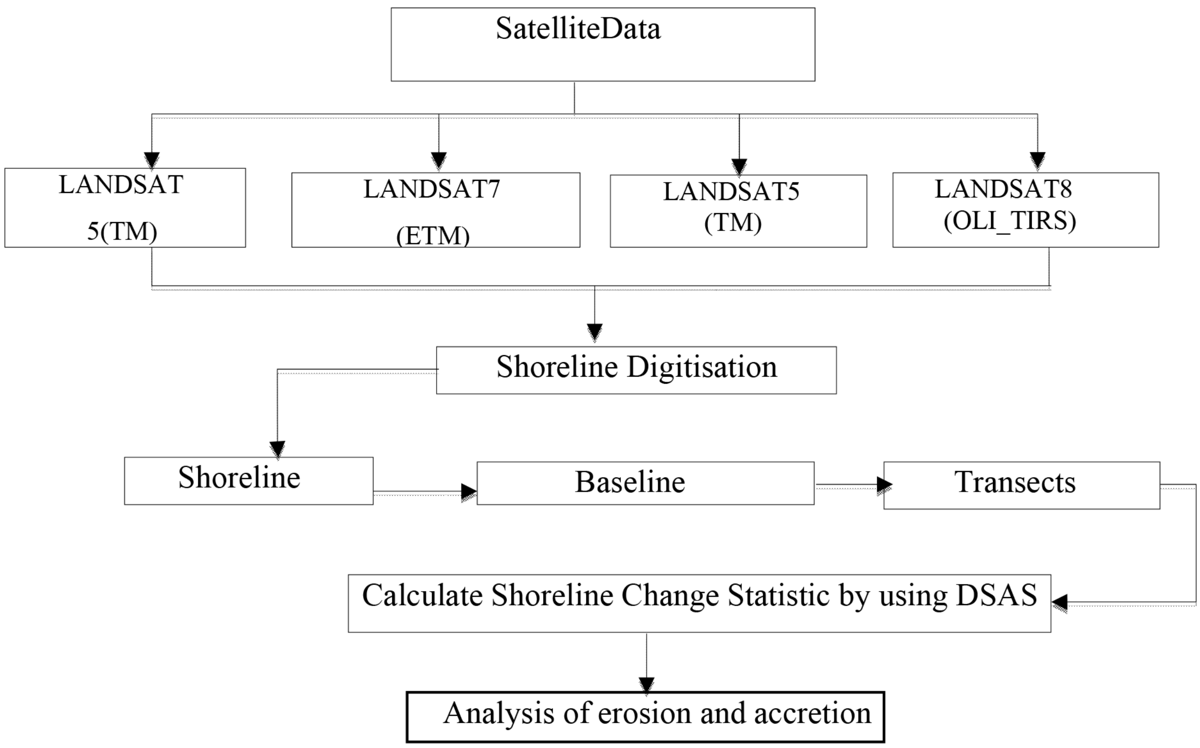

Figure 2: Methodology of the study.

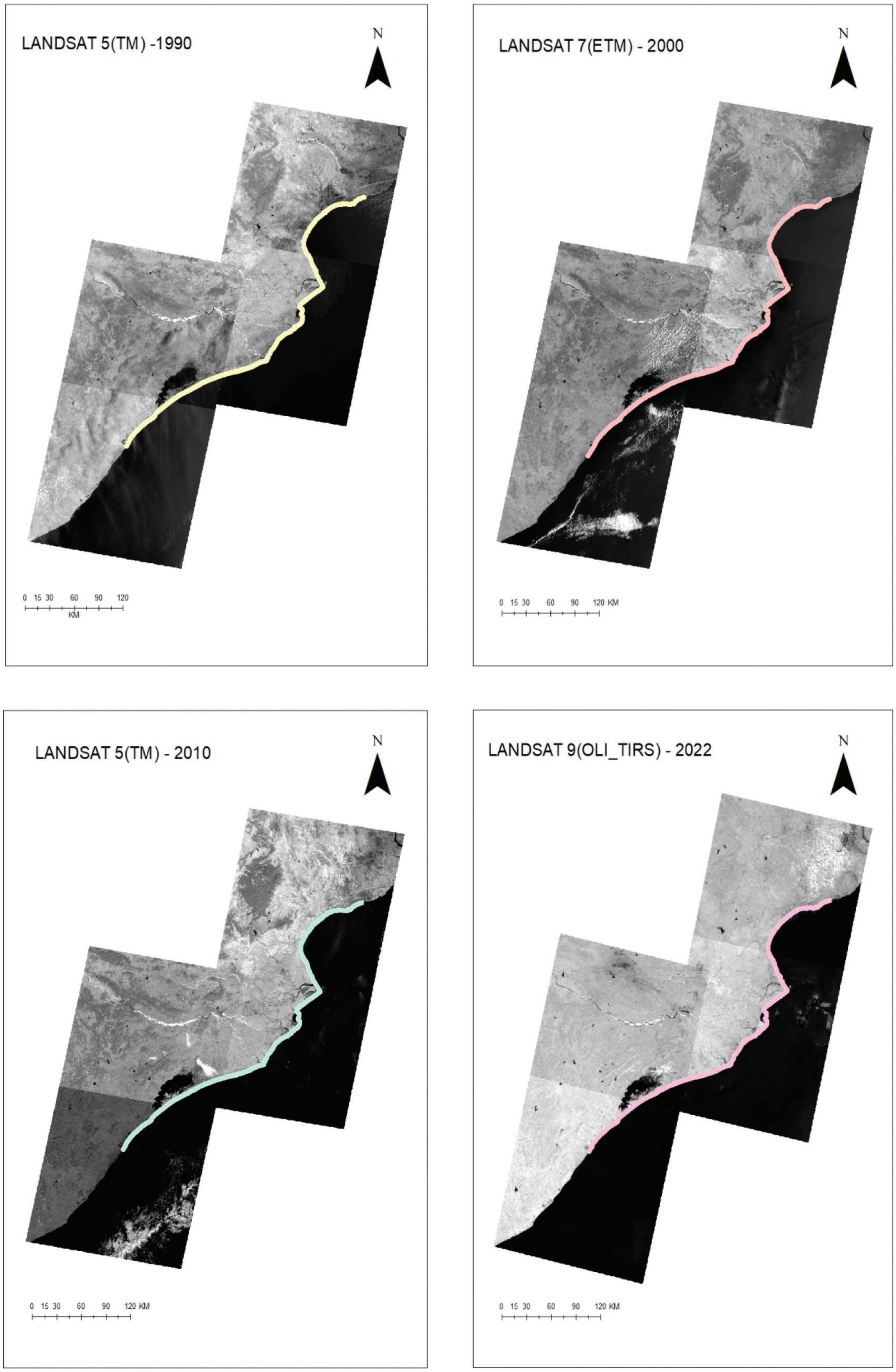

Figure 3: Shoreline digitised along the Odisha coastline for the years 1990, 2000, 2010 and 2022.

generated by using DSAS tool to 1500 m length with 500 m spacing between transects. Then select baseline data and shoreline data in default parameters and cast the transect line to study the changes occurred in Odisha coast. After creating transect line run the DSAS tool to get statistical Output table which includes End Point Rate (EPR) and Linear Regression Rate (LRR) value.

Results and Discussions

To analyse the shoreline changes the coastline is divided into five zones according to number of transects. Each transect has 200 transect lines. Using the EPR and LRR methods, the rate of shoreline change for five zones of the Odisha coast has been examined.

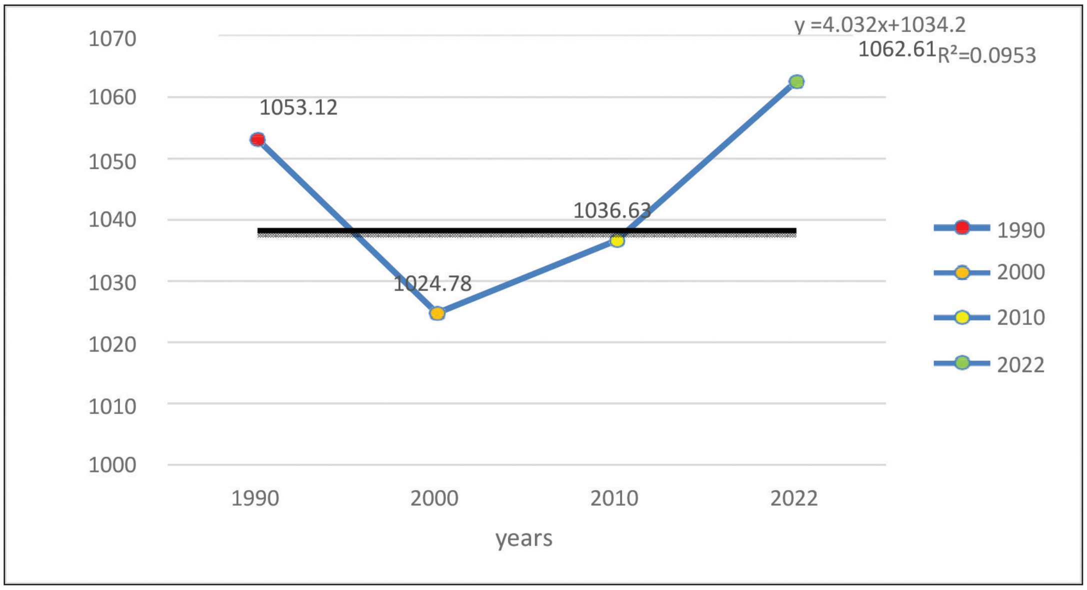

Figure 4: Linear regression rate calculated from the DSAS results.

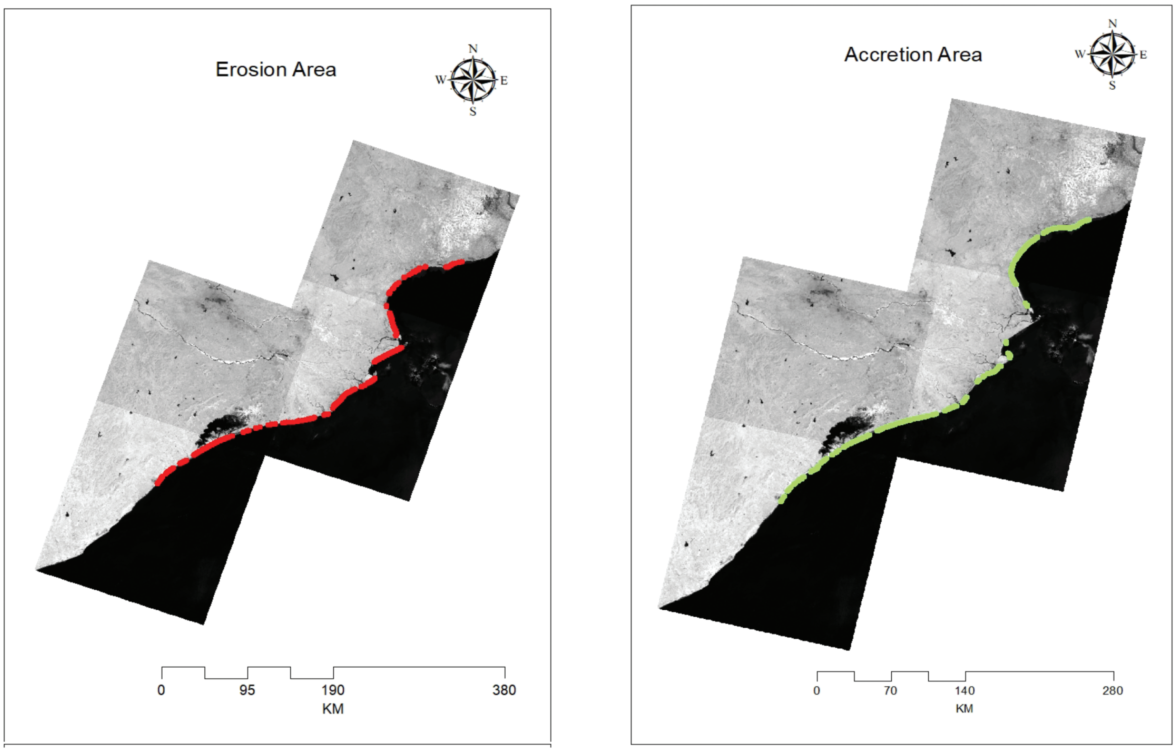

Figure 5: Erosion and accretion area highlighted along the Odisha coastline.

The End Point Rate (EPR) technique determines the rate of shoreline movement by dividing the distance of shoreline movement by the length of time between the oldest and most recent coastline. In the statistics module offered by DSAS, the distance values for each measurement point are used to calculate the rates of shoreline change.

Using the End Point Rate formula (Equation 1), which is directly proportional to shoreline lengths and inversely proportional to the interval between the oldest and most recent shorelines, we may calculate the rate of erosion and accretion.

End Point Rate =

$$\frac{\text{Distance (in m)}}{\text{Time between the oldest and most recent shoreline}} \quad (1)$$

The least squares regression line is fitted to many shoreline location points for a certain transect using the linear regression rate (LRR) approach, as demonstrated in Figure 4. By plotting the points where the shorelines are intersected by transects and thereby calculating the linear regression equation by Equation 2,

$$L = b + mx \quad (2)$$

where 'L' represents the distance value from the baseline where the actual baseline is buffered at a distance of 1500 m from the shoreline taken in the year 2010, 'x' represents the period of data collection, and 'm' indicates the slope of the fitted plot line. The coastline rate of change along with each transect line for all periods 1990, 2000, 2010 are represented in Figure 4.

To ensure consistency and clarity in presenting the transect data, a standardised format has been adopted across all results. The transect lines corresponding to the periods 1990, 2000, and 2010 have been uniformly labelled and displayed in a manner that enhances the interpretability of the rate of change statistics. This standardisation not only improves the visual representation of the data but also ensures that the trends in erosion and accretion along the Odisha coastline are comprehensible at a glance, facilitating a clearer understanding of spatial and temporal variations in shoreline dynamics.

The LRR findings are compactable for linear regression rate changes in shoreline with respect to both space and time.

The change statistics computed along the Odisha coastline are spatially mapped as in Figure 5 and presented in Table 2, respectively.

The table provides detailed insights into the transect data for shoreline changes across five zones. Each zone consists of 200 transects, and the data measures the mean rates of shoreline change, as well as the proportion of transects experiencing erosion and accretion.

Out of the 200 transects in Zone 1, 55.6% (which amounts to 112 transects) are subject to erosion, where the highest rate of erosion observed is -7.29 m/year, and the mean erosion rate across these transects is -1.530 m/year. Meanwhile, the remaining 44.4% (88 transects) experience accretion, with a maximum accretion rate of 14.72 m/year and a mean accretion rate of 2.881 m/year. The data suggest that most of the transects in this zone are eroding, though some are accumulating sediment at a considerable rate, balancing the net mean shoreline change.

In Zone 2, 28.19% of the transects (about 56 transects) are affected by erosion, with a maximum rate of -6.77 m/year and a mean rate of -1.670 m/year. However, 71.81% of the transects (144 transects) are witnessing accretion, with a maximum accretion rate of 11.48 m/year and a mean rate of 2.241 m/year. This zone shows a strong accretional trend, where the majority of the transects exhibit shoreline growth, while a smaller number are eroding at relatively lower rates.

Out of the 200 transects in Zone 3, **56.06%** (112 transects) are experiencing erosion, with the highest erosion rate recorded at **-14.01 m/year** and a

Table 2: Statistical analysis of digitised shoreline of Odisha coast

Zone No	*Number of transects*	*Mean rate (m/year)*	*% Erosion*	*Erosion rate (m/year)*		*% Accretion*	*Accretion rate (m/year)*	
				Max	*Mean*		*Max*	*Mean*
1	200	1.351	55.6	-7.29	-1.530	44.4	14.72	2.881
2	200	0.571	28.19	-6.77	-1.670	71.81	11.48	2.241
3	200	1.414	56.06	-14.01	-5.115	43.94	18.63	3.701
4	200	2.694	80.68	-23.99	-10.291	19.32	18.45	7.597
5	200	3.403	15.55	-9.66	-2.954	84.45	29.98	6.357

mean erosion rate of **-5.115 m/year**. The remaining **43.94%** of the transects (88 transects) are subject to accretion, with a maximum accretion rate of **18.63 m/year** and a mean rate of **3.701 m/year**. Zone 3 demonstrates a strong erosional process, where the majority of the transects are losing land rapidly. However, accretion is occurring in a significant number of transects, with some experiencing very high accretion rates.

In Zone 4, **80.68%** of the transects (around 161 transects) are affected by erosion. The maximum erosion rate is **-23.99 m/year**, while the mean rate is **-10.291 m/year**, indicating a severely eroding coastline for most transects. On the other hand, **19.32%** of the transects (39 transects) are undergoing accretion, with a maximum rate of **18.45 m/year** and a mean accretion rate of **7.597 m/year**. This zone is highly erosional, with a large number of transects suffering from significant land loss. Only a few transects are accreting, but these transects show high accretion rates.

In Zone 5, **15.55%** of the transects (about 31 transects) are experiencing erosion, with a maximum erosion rate of **-9.66 m/year** and a mean rate of **-2.954 m/year**. Conversely, the vast majority, **84.45%** of the transects (169 transects), are seeing accretion, with a maximum rate of **29.98 m/year** and a mean accretion rate of **6.357 m/year**. Zone 5 is predominantly accretional, with a substantial number of transects accumulating land at high rates, while only a small fraction of transects are eroding.

The transect data paints a detailed picture of the shoreline dynamics in each zone. In Zones 1 and 3, there is a relatively even split between erosion and accretion, though erosion slightly outweighs accretion. Zone 2 is predominantly accretional, with most transects gaining land. Zone 4 is highly erosional, with the vast majority of transects losing land at significant rates. Finally, Zone 5 demonstrates the opposite trend, where the vast majority of transects are accreting, with only a small percentage experiencing erosion.

To further support the analysis, visual aids such as graphs, charts, and spatial maps have been included to illustrate key findings clearly. These visuals highlight the rates of erosion and accretion over the study period, making complex data more accessible and allowing for a clear comparison of affected zones.

In conclusion, concrete policy recommendations have been developed based on the findings of this study. These recommendations focus on sustainable coastal management strategies that prioritise both environmental conservation and socio-economic stability.

Conclusions

The average erosion and accretion rate throughout the Odisha coast ranges from 0.571 metre/year to 3.403 metre/year, according to this study's clear analysis of shoreline change rates utilising the End Point Rate (EPR) and Linear Regression Rate (LRR) methodologies. In the study area, the average rate of erosion is -2.803 metre/year and the average accretion rate is 4.086 metre/year. In Odisha shoreline separated into five zone according to the number of the transect line, in one zone has 200 transects. Zone 1 has 200 transects the percentage of erosion is 55.6% maximum rate in erosion is -7.29 and accretion is 44.4% maximum rate in accretion is 14.72. Zone 2 has 200 transects the percentage of erosion is 28.19% maximum rate in erosion is -6.77 and accretion is 71.81% maximum rate in accretion is 11.48. Zone 3 has 200 transects the percentage of erosion is 56.06% maximum rate in erosion is -14.01 and accretion is 43.94% maximum rate in accretion is 18.65. Zone 4 has 200 transects the percentage of erosion is 80.68% maximum rate in erosion is -23.99 and accretion is 19.32% maximum rate in accretion is 18.45. Zone 5 has 200 transects the percentage of erosion is 15.55% maximum rate in erosion is -9.66 and accretion is 84.45% maximum rate in accretion is 29.98.

References

Ashton, A. and A.B. Murray (2006). High-angle wave instability and emergent shoreline shapes: Wave climate analysis and comparisons to nature. *Journal of Geophysical Research: Earth Surface*, **111(F4):** F04012.

Baig, M.R.I., Ahmad, I.A., Shahfahad, T.M. and A. Rahman (2020). Analysis of shoreline changes in Vishakhapatnam coastal tract of Andhra Pradesh, India: An application of digital shoreline analysis system (DSAS). *Annals of GIS*, **26(4):** 361-376.

Bird, E. (2008). Coastal Geomorphology: An Introduction (2nd ed.). John Wiley & Sons.

Boak, E.H. and I.L. Turner (2005). Shoreline definition and detection: A review. *Journal of Coastal Research*, **21(21):** 688-703.

Crowell, M., Douglas, B.C. and S.P. Leatherman (1997). On forecasting future U.S. shoreline positions: A test of algorithms. *Journal of Coastal Research*, **13(4):** 1245-1255.

Douvere, F. (2008). The importance of marine spatial planning in advancing ecosystem-based sea use management. *Marine Policy*, **32(5):** 762-771.

Kar, P.K., Mohanty, P.K., Pradhan, S., Behera, B., Padhi, S.K. and P. Mishra (2021). Shoreline change along Odisha coast using statistical and geo-spatial techniques. *Journal of Earth System Science*, **130(4):** 1-20.

Karunanidhi, D., Aravinthasamy, P., Subramani, T., Kumar, D. and G. Venkatesan (2021). Chromium contamination in groundwater and Sobol sensitivity model based human health risk evaluation from leather tanning industrial region of South India. *Environ. Res.*, **199:** 111238.

Klein, R.J., Nicholls, R.J. and F. Thomalla (2001). Resilience to natural hazards: How useful is this concept? *Global Environmental Change Part B: Environmental Hazards*, **3(1):** 35-45.

Nassar, K., Fath, H., Mahmod, W.E., Masria, A., Nadaoka, K. and A. Negm (2018). Automatic detection of shoreline change: case of North Sinai coast, Egypt. *Journal of Coastal Conservation*, **22(6):** 1057-1083.

Nordstrom, K.F. (2000). Beaches and dunes of developed coasts. Cambridge University Press.

Sivakumar, Balasundaram, V., Venkatesan, G. and S.V. Saravanan (2014). Effect of tamarind kernel powder for treating dairy industry wastewater. *Pollut. Res*., **33:** 519-523.

Suleyman, A., Muyibi Ahmed Hissein, M., Birima Thamer and A. Mohammed (2004). Conventional treatment of surface water using *Moringa oleifera* seeds extract as a primary coagulant. *IIUM Eng J*, **5:** 25-35.

Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L. and A. Ergul (2009). Digital Shoreline Analysis System (DSAS) version 4.0—An ArcGIS extension for calculating shoreline change (No. 2008-1278). US Geological Survey.

Toure, S., Diop, O., Kpalma, K. and A.S. Maiga (2019). Shoreline detection using optical remote sensing: A review. *ISPRS International Journal of Geo-Information*, **8(2):** 75.

Venkatesan, G. and P. Raj Chandar (2012). Possibility studies and parameter finding for interlinking of Thamirabarani and Vaigai Rivers in Tamil Nadu, India. *Int. J. Earth Sci. Eng.*, **1:** 16-26.

Venkatesan, G. and T. Subramani (2016a). Case study on environmental impact due to industrial waste water in Vellore District, Tamil Nadu, India using geospatial techniques. *Middle East J. Sci.Res*. **26:** 152-159.

Venkatesan, G., Subramani, T., Sathya, U. and D. Priyadarsi Rao (2020a). Seasonal changes in groundwater composition in an industrial center of south India and quality evaluation for consumption and health risk using geospatial methods. *Geochemistry*, **80:** 125651. doi: 10.1016/j.chemer.2020.125651.

Venkatesan, G. and T. Subramani (2019). Reduction of hexavalent chromium to trivalent chromium from tannery effluent using bacterial biomass. *Indian J. Geo-Mar. Sci*., **48:** 528-534.

Venkatesan, G., Subramani, T., Karunanidhi, D., Sathya, U. and P. Li (2020b). Impact of precipitation disparity on groundwater fluctuation in a semi-arid region (Vellore district) of southern India using geospatial techniques. *Environ. Sci. Pollut. Res. Int.*, **28:** 18552.

Venkatesan, G., Subramani, T., Sathya, U. and D. Karunanidhi (2020c). Evaluation of chromium in vegetables and groundwater aptness for crops from an industrial (leather tanning) sector of South India. *Environ Geochem Health*, **43:** 96-1008. https://doi.org/10. 1007/s10653-020-00665-5.

Venkatesan, G. and T. Subramani (2018). Environmental degradation due to the industrial wastewater discharge in Vellore District, TamilNadu, India. *Indian J. Geo-Mar. Sci*., **47:** 2255-2259.

Venkatesan, G., Aishwaryya, R., Renjinny, A.S. and M. Pavithra (2014). Surface & groundwater management a remote sensing and GIS based. *Int. J. Sci. Res. Dev.*, **1:** 158–162.

Venkatesan, G. and T. Subramani (2016b). Parameter Finding for Case Study of Environmental Degradation Due to Industrial Pollution in Vellore, Tamil Nadu, India Using Remote Sensing and GIS Techniques. Paper presented at the International Conference on Science and Innovative Engineering (ICSIE 2016b), Jawahar Engineering College, Chennai, India, pp.1-7.

Venkatesan, G., Kuberan, M., Jegadeesh, S. and B.V. Praveen (2023a). Carbon capture and storage with ionic liquids; industrial flue gas trapping in calcination process. *Asian Journal of Water, Environment and Pollution*, **20(2):** 85-91. DOI 10:3233/AJW230028

Venkatesan, G., Joyal Isac, S., Jerome Nithin Gladson, G. and S.D. Amala (2022). Demarcation of non-carcinogenic risk zones based on the intake of contaminated groundwater in an industrial area of southern India using geospatial techniques. *Desalination and Water Treatment*, **274:** 140-149. doi:10.5004/dwt.2022.28901