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COASTAL LANDUSE LAND COVER CHANGE AND TRANSFORMATIONS IN-BETWEEN CUDDALORE AND NAGORE, SOUTH EAST COAST OF INDIA USING REMOTE SENSING AND GIS

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Abstract

This study investigates the Land Use and Land Cover (LULC) changes in the dynamic coastal zone between Cuddalore and Nagore on the southeast coast of India, using Remote Sensing and Geographic Information System (GIS). The study spans four decades from 1980 to 2020 and aims to understand the relationships between human activities and the coastal environment in an area prone to natural hazards such as cyclones, coastal erosion, and occasional tsunamis. The research classifies LULC changes into six classes: plantation, coastal wetland, fallow land, barren land, built-up land, and water body. The results reveal a reduction in plantations, coastal wetlands, and fallow land, while an improvement is observed in barren land, built-up land, and water bodies from 1980 to 2020. The study emphasizes the need for immediate attention to increasing mangrove forests as a natural protection measure for coastal wetlands against calamities. The LULC maps' overall accuracy assessment and Kappa coefficient values demonstrate substantial reliability. The information derived from this study can be valuable for future management plans related to urbanization and the sustainable development of the region. The methodology used in this study, involving remote sensing and GIS techniques, can be adapted for similar studies in coastal regions worldwide, forming a basis for strategic planning to protect coastal communities and the environment.

Keywords: Land use land cover, Change detection, Kappa coefficient, Remote sensing, Image processing and GIS

1. Introduction

In recent times, the significance of Land Use and Land Cover (LULC) information has become pivotal in shaping policies, influencing economic decisions, and administering regions worldwide (Rwanga & Ndambuki, 2017). The spatial data concerning land surface utilities holds paramount importance for environmental protection and strategically planning development activities. LULC classification plays a crucial role by providing essential land surface data, which serves as a key input for environmental modeling, climate change assessments, and policy development (Disperati et al., 2015). The dynamics of spatial-temporal changes in LULC represent a complex phenomenon influenced by various natural, social, and economic factors (Lansine and Liqin, 2010). Coastal regions, in particular, face the impact of numerous natural disasters, including storms, cyclones, floods, tsunamis, and erosion (Arunachalam et al., 2011; Boori et al., 2015; Kongeswaran and Karikalan, 2015). The projected rise in sea levels by 2100, as outlined by the Intergovernmental Panel on Climate Change (IPCC, 2007), poses a significant threat to global coastal communities. Additionally, coastal areas are highly susceptible to LULC changes resulting from industrialization and urbanization (Sivakumar et al., 2017). Assessing LULC changes is imperative for formulating effective management plans in coastal regions. Comprehensive knowledge of LULC, presented through maps and statistical evidence, plays a vital role in urban planning and land management. The integration of remote sensing and GIS techniques facilitates the creation of LULC maps (Praveen et al., 2013; Mishra et al., 2019; Muthusamy et al., 2010; Muthusamy et al., 2018). Rapid urbanization along coastal zones, driven by construction practices, has simultaneous repercussions on the coastal environment (Kongeswaran, 2019). The southeast coast of India has witnessed substantial reduction in its extent due to reclamation, dredging, tipping, and other anthropogenic activities (Prabhakar and Tiwari, 2015). This study is designed to evaluate LULC changes in a specific part of the southeast coast of India, employing remote sensing and image processing techniques integrated with GIS (Prakasam, 2010; Rajiv et al., 2019; Rwanga & Ndambuki, 2017). The assessment of LULC changes is essential for comprehending the current state of a coastal region, contributing to sustainable development, future planning, and effective management. The dynamic natural processes in the Cuddalore to Nagore coastal region expose it to various hazards,

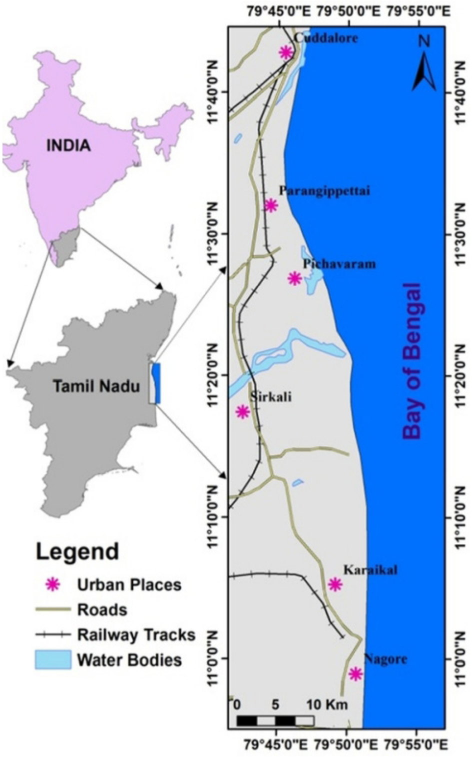

Fig. 1. Study area from Cuddalore to Nagore coastal zone

necessitating a detailed understanding of LULC shifts. This study aims to provide insights into these shifts to establish an optimized strategic plan for the development and protection of the vulnerable coastal zone (Kongeswaran and Karikalan, 2021; Thangaraj and Karthikeyan, 2022; Selçuk, 2008). The rapid transformations in coastal landforms underscore the need for a nuanced approach to safeguarding and promoting the sustainable development of this crucial coastal area. This study focuses on the southeast coast of India, specifically the area between Cuddalore and Nagore, which has been significantly impacted by natural hazards. The research aims to assess LULC changes from 1980 to 2020 and highlights the importance of understanding these changes for sustainable development and future planning.

2. Study area

The study area extends from 10o81’07” to 11^{o}77’76” latitude and from 79^{o}85’80” to 79^{o}69’73” longitude, covering the Ponnaiyar river basin in the north and the Uppanar river basin in the south. The region, with a total geographical area of 1423 km^{2} and a coastline of 107 km, relies on agriculture, tourism, fishing, and aquaculture for economic revenue. The area is characterized by various geological formations, a flat landscape, and susceptibility to natural phenomena like cyclones and storms.

3. Methodology

The adopted methodology, outlined after an exhaustive literature review, is presented as a flow chart in Fig. 2. Toposheets indexed as 58 M/10, 58 M/13, 58 M/14, 58 M/15, 58 M/16, 58 N/11, 58 N/13, and 58N/15 obtained from the Survey of India (SOI) were utilized to create the base map for the study area. Satellite data consisting of temporal imageries for the years 1980, 1990, 2000, 2010, and 2020 were sourced from the United States Geological Survey (USGS) websites (refer to Table 1) (Sivakumar et al., 2022). The preprocessed satellite images were imported into ArcGIS 10.8 and clipped to the study area’s boundary. Saga GIS (v.2.3.2) image processing application was employed to generate true-color (RGB) composite maps and false-color (GR-IR) composite maps (Fig. 3) for each selected year, facilitating analysis and visual interpretation (Sharun et al., 2011).

Two general methods for image classification, namely supervised and unsupervised, are available (Tiwari and Khanduri, 2011). The unsupervised classification images for the selected years were produced using the cluster analysis for grids module of Saga GIS. The “Hill-climbing” classification technique, following the approach proposed by Dempster et al. (1977), was applied in the unsupervised method. The unsupervised processing generated a total of 500 cluster classes, later grouped into six major classes through visual interpretation. These major classes are identified as barren land (BL), built-up land (BUL), coastal wetland (CW), fallow land (FL), plantation (PL), and water body (WB) (Fig. 4). Detailed descriptions of these classes are provided in Table 2. The accuracy of the processed Land Use and Land Cover (LULC) maps was evaluated using the formulas (1) and (2) for overall accuracy and Kappa coefficient, respectively.

$$A_y = \frac{\sum Cp}{N} \qquad (1)$$

Where, ‘Ay’ is the overall accuracy in year y, ‘Cp’ is the correctly classified pixels in year ‘y’ and ‘N’ is the total number of reference pixels in selected year.

$$K = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{r}(x_{i+} \times x_{+i})} \qquad (2)$$

Where, ‘K’ is the Kappa coefficient, ‘N’ denotes the total number of pixels taken for the observation, ‘r’ is the number of rows and columns in an error matrix, ‘xii’ is the observation in row i and column i, ‘xi+’ is sum of observations in row i and ‘x+i’ is the sum of observations in column i.

The temporal change of each class is calculated by subtracting the obtained results of previous year from the result of later year. The change rate of each class is computed by the below formula 3. The interchanges of each class between the selected years were determined by change detection module in Saga GIS. This technique was applied to determine the aerial extent of the inter changed classes for the periods 1980 to 1990, 1990 to 2000, 2000 to 2010, 2010 to 2020 and 1980 to 2020 respectively.

$$Cr = \frac{(A_i - A_j)}{i - j} \qquad (3)$$

Here, ‘Cr’ is the change rate, Ai (earlier) and Aj (later) is the area of class between selected years, ‘i’ is the earlier year and ‘j’ is the later year which is the period taken for this study.

The LULC maps pertaining of five different periods were used for post-classification comparison, which facilitated the estimation of changes in the LULC category and change dynamics (Maggie et al. 2019). The post-classification comparison is the most commonly used quantitative method of change detection with fairly gives reliable results. It requires separately generated spectral classification findings from separate data sets, accompanied by a pixel-by-pixel or segment-by-segment analysis to identify differences in groups (Fig. 5).

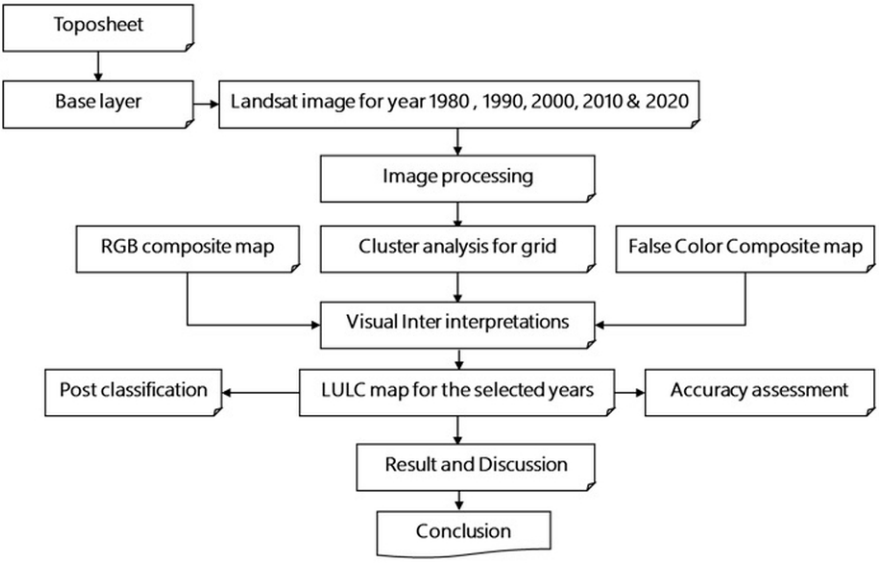

Fig. 2. Flow chart of the adopted methodology

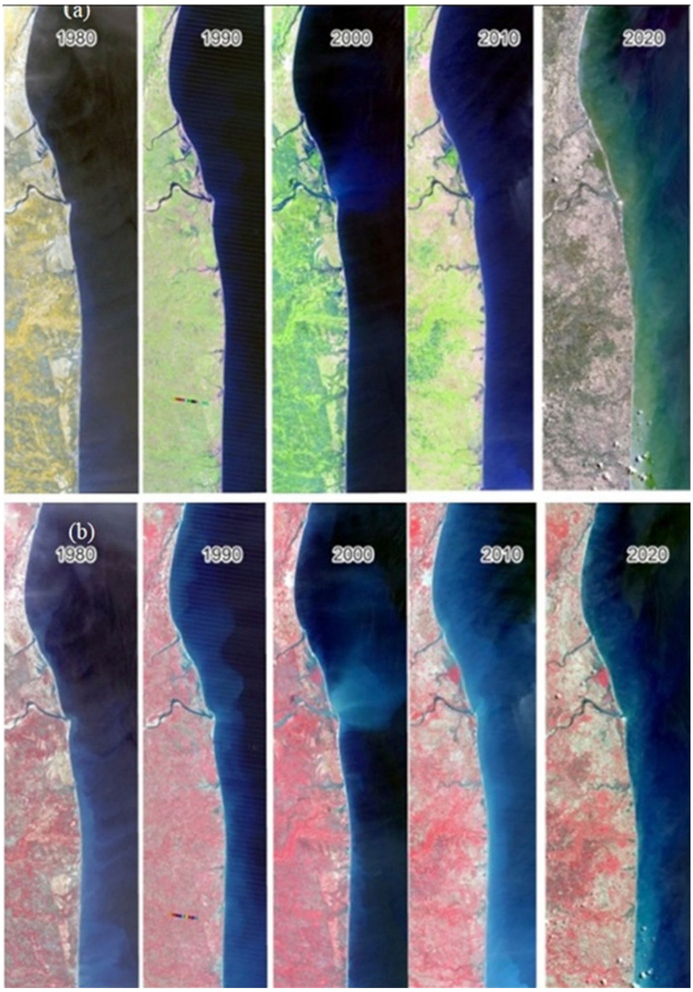

Fig. 3. (a) True Colour Composite Maps (Red, Green & Blue) and (b) False Colour (Green, Red & Infrared) Composite Maps

Table 1. Particulars of satellite Imageries used

Satellite	Scene Identifier	Acquired on	Sensor Mode	Coordinate System
Landsat_3	LM03_L1TP_153052_19800824	24-08-1980	Multispectral Scanner (MSS)	WGS84 /UTM Zone 44N
Landsat_5	LT05_L2SP_142052_19900518	18-05-1990	Multispectral Scanner (MSS) & Thematic Mapper (TM)	WGS84 /UTM Zone 44N
Landsat_7	LE07_L2SP_142052_20001028	28-10-2000	Enhanced Thematic Mapper Plus (ETM+)	WGS84/ UTM Zone 44N
Landsat_5	LT05_L1TP_142053_20101016	16-10-2010	Multispectral Scanner (MSS) & Thematic Mapper (TM)	WGS84/ UTM Zone 44N
Landsat_8	LC08_L2SP_142052_20200605	03-10-2020	Operational Land Imager (OLI) & Thermal Infrared Sensor (TIRS)	WGS84/ UTM Zone 44N

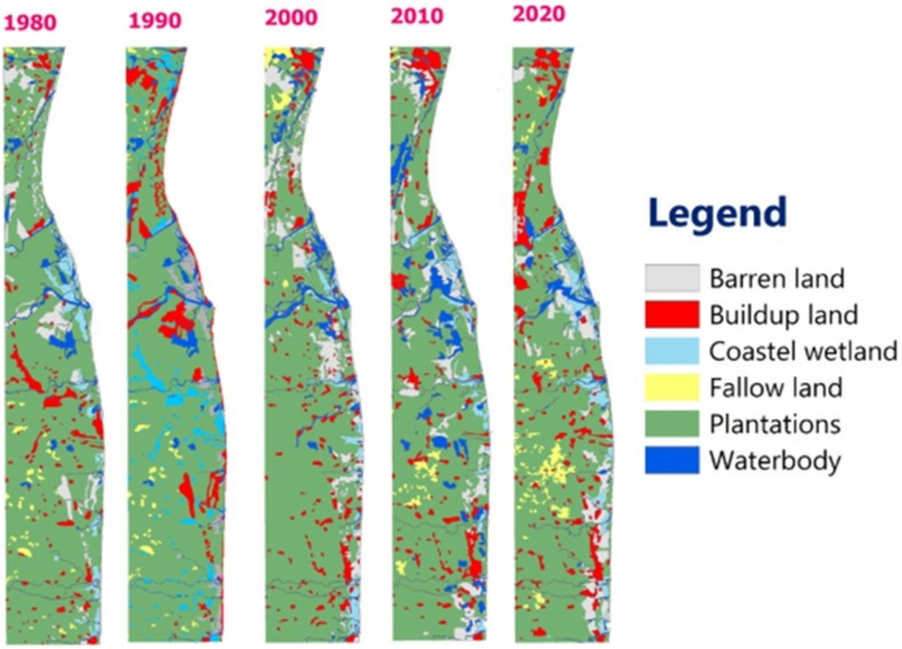

Fig. 4. Land Use & Land Cover classified maps

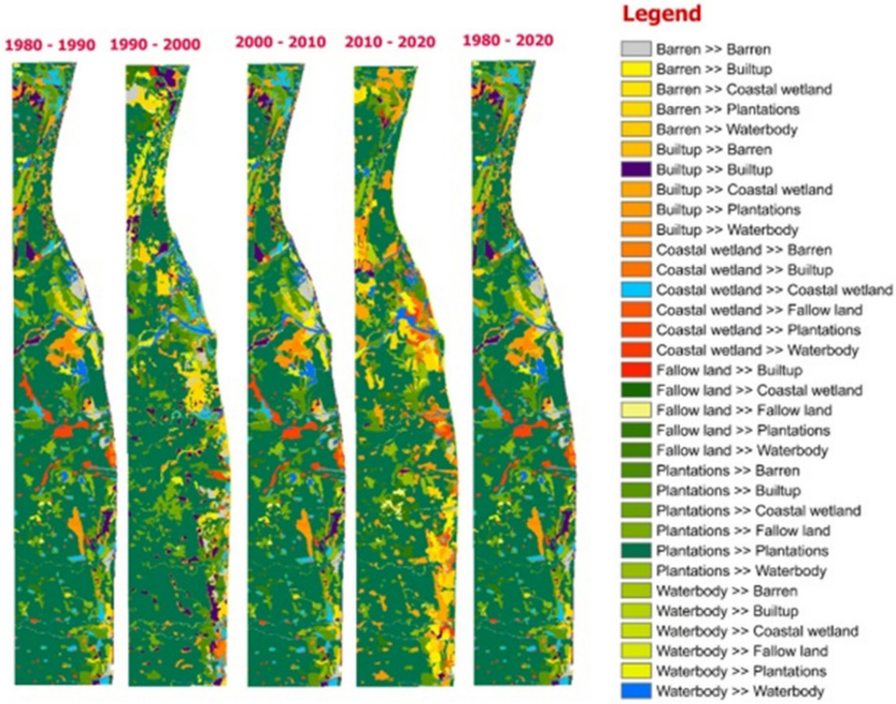

Fig. 5. Land use/land cover change analysis maps

Table 2. Land cover classification scheme

S.No	Class	Description
1	Barren land (BL)	Areas with no vegetation cover, stock quarry, stony areas
2	Built-up land (BWL)	Residential, commercial, industrial, transportation and facilities
3	Coastal wetland (CW)	Coastal region consisting of marshes or swamps; saturated land
4	Fallow land (FL)	Uncultivated crop land
5	Plantations (PL)	Agriculture fields, forest, bushes and scrubs
6	Water body (WB)	All the water-logged areas (River/ Streams/Lakes)

4. Results and Discussion

The obtained results are summarized in Table 1, while the histogram in Figure 6 visually represents the mutual differences in each class for the selected years. Pie charts in Figure 6 illustrate the overall percentage of classes present at the time of image capture. The LULC classification for 1980 indicates that plantation dominates the land use, covering approximately 73.61% of the total area. This is followed by coastal wetland (12.01%), water body (7.40%), built-up land (3.41%), fallow land (2.45%), and barren land (1.12%). In 1990, plantation still covered the majority, at 74.17%, followed by barren land (8.78%), built-up area (6.30%), water body (5.11%), coastal wetland (4.16%), and fallow land (1.48%). By 2000, plantation, coastal wetland, and fallow land decreased to 70.11%, 3.06%, and 1.38%, respectively. In contrast, barren land, built-up area, and water body increased to 11.65%, 7.45%, and 6.35%, respectively. The 2010 results show an increase in built-up area to 10.67%, followed by coastal wetland (3.24%) and fallow land (3.30%). There is a decrease in plantation (68.96%), barren land (9.23%), and water body (4.61%). In 2020, plantation still dominates with 69.65%, followed by barren land (11.96%), built-up land (8.30%), water body (7.59%), coastal wetland (1.35%), and fallow land (1.16%). Validation of the LULC classification maps is conducted through overall accuracy assessment and Kappa statistics, as provided in Table 4. The overall accuracy of the LULC classification results exceeds 75% for all selected years, with Kappa coefficient values ranging between 0.73 and 0.80, meeting substantial rating criteria (Rwanga and Ndambuki, 2017). Temporal differences in each class area are detailed in Table 5 and visualized as a bar chart in Figure 8, indicating a 9.95% increase in barren land and a 6.69% decrease in plantations from 1980 to 2020. The change rate of each class for the study period is presented in Table 6, highlighting an increasing trend in barren land, built-up land, and water body, and a decreasing trend in coastal wetlands, plantations, and fallow land. The overall change matrix for the period from 1980 to 2020, produced using a pixel-by-pixel comparison method, is provided in Table 7 and depicted as a bar chart in Figure 9. The results show that a maximum of 6.57% of plantation land has transformed into barren land, indicating deforestation, reduced agricultural practices, and encroachment of water bodies for seasonal cultivation. The overall change matrix (Table 8) for the same period reveals the conversion of approximately 246.3 km2 of plantation land into other classes, primarily barren land (79.89 km2) and built-up land (48.54 km2). Barren land, in turn, has been converted into plantations, covering an area of 53.68 km2, showcasing afforestation activities and new cultivation practices. The impact of natural hazards in the coastal zone has adversely affected the economy of coastal communities, leading to migrations inland, resulting in the abandonment of once-cultivated land, which subsequently becomes barren land. The coastal region is undergoing rapid urbanization, driven by several factors such as the manufacturing sectors, a burgeoning tourism industry, and an influx of migrants from various parts of area. This urbanization trend has resulted in the transformation of erstwhile agricultural land into residential, commercial, and industrial zones. Notably, the coastal area hosts diverse industries, including textiles, chemicals, and pharmaceuticals, whose expansion has further contributed to the conversion of agricultural tracts into industrial spaces. Renowned for its tourist appeal, the coastal region of study area has witnessed significant infrastructural development to accommodate the growing tourism sector. Agricultural land has been repurposed for the construction of hotels, resorts, and various amenities to support the burgeoning tourist influx. Despite these changes, agriculture remains a pivotal economic activity in the coastal region. However, there has been a discernible decline in agricultural production in recent years. Factors such as water scarcity, soil salinity, and pest-related challenges have collectively contributed to this decline. Consequently, to cope with the diminishing agricultural output, there has been a notable shift in land use, with agricultural land being repurposed for urban and industrial development. In essence, the coastal region of study area is grappling with a multifaceted transformation characterized by urbanization fueled by various sectors, expansion of industries, burgeoning tourism, and the challenges faced by traditional agriculture. This dynamic interplay of factors is reshaping the landscape and land-use patterns in the region.

Table 3. Calculated Area for each class in selected years (in %)

LULC Class	1980	1990	2000	2010	2020
Barren land	1.12	8.78	11.65	9.23	11.96
Built-up land	3.41	6.30	7.45	10.67	8.30
Coastal wetland	12.01	4.16	3.06	3.24	1.35
Fallow land	2.45	1.48	1.38	3.30	1.16
Plantations	73.61	74.17	70.11	68.96	69.65
Water body	7.40	5.11	6.35	4.61	7.59

Table 4. Validation results for the LULC classification maps

Year	Overall Accuracy	Kappa coefficient (K)
1980	83.33%	0.80
1990	80.00%	0.76
2000	82.35%	0.79
2010	77.58%	0.73
2020	79.62%	0.76

Table 5. Rate of changes in each class for the periods

Class	1980-1990	1990-2000	2000-2010	2010-2020	1980-2020
Barren land	7.66	2.87	-2.26	1.68	9.95
Built-up land	2.89	1.15	3.11	-2.47	4.67
Coastal wetland	-7.85	-1.10	1.35	-1.21	-8.80
Fallow land	-0.97	-0.10	1.79	-1.94	-1.22
Plantations	0.56	-4.06	-2.45	-0.74	-6.69
Water body	-2.29	1.24	-1.54	3.20	0.60

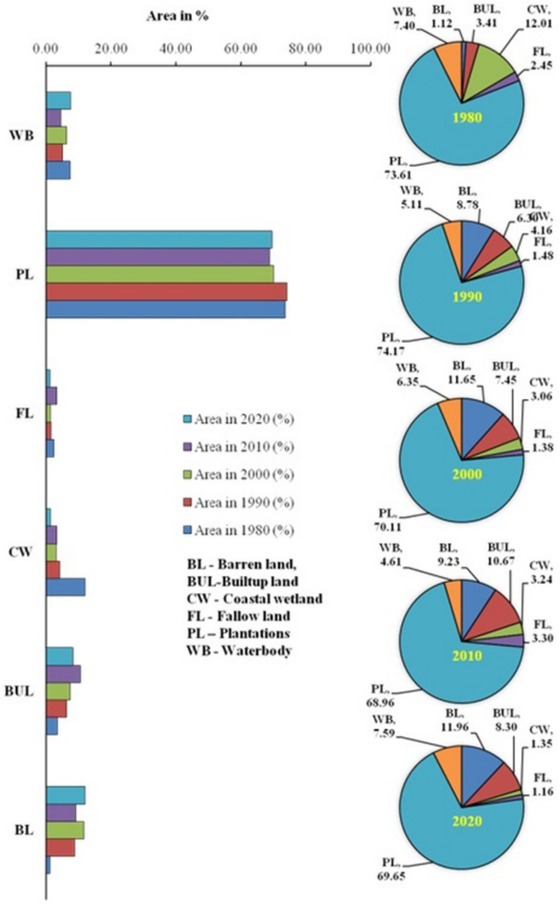

Fig. 6. Histogram and Pie-charts illustrates the mutual and overall percentages of all classes

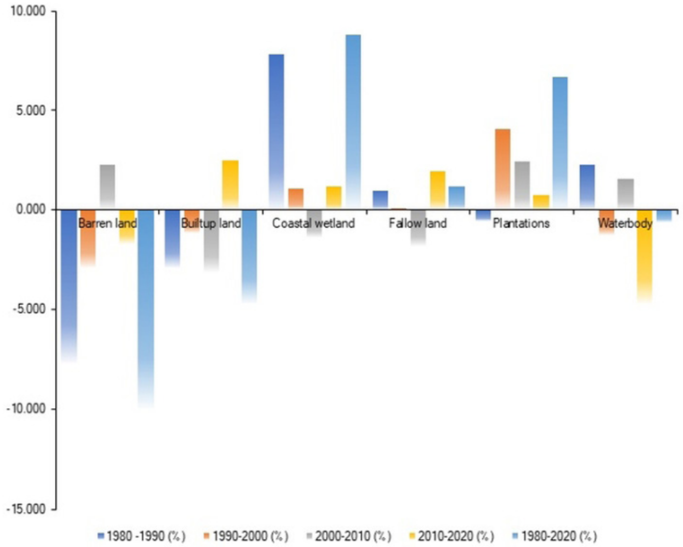

Fig. 7. Difference in class area in selected periods

Table 6. Change rate of each class for the study period

Period	No. of Years	BL	BUL	CW	FL	PL	WB
1980-1990	10	0.77	0.29	-0.78	-0.10	0.06	-0.23
1990-2000	10	0.29	0.12	-0.11	-0.01	-0.41	0.12
2000-2010	10	-0.23	0.31	0.14	0.18	-0.24	-0.15
2010-2020	10	0.17	-0.25	-0.12	-0.19	-0.07	0.32
1980-2020	40	0.25	0.12	-0.22	-0.03	-0.17	0.02

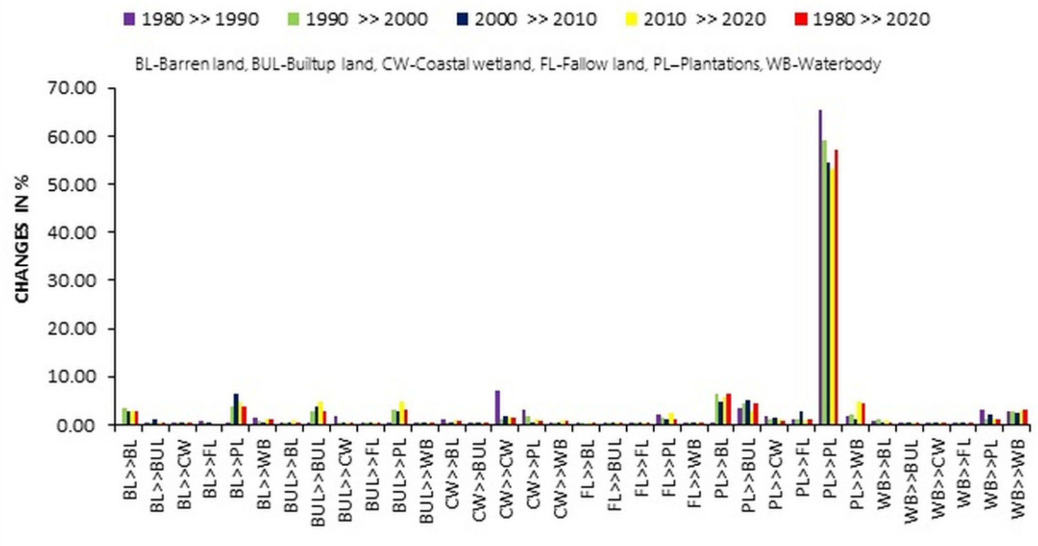

Fig. 8. Bar-Chart shows the temporal variation interchanged classes

Table 8. The overall change matrix of LULC in sq.km from 1980 to 2020

		LULC 2020							
	Row Labels	Barren land	Builtup land	Coastal wetland	Fallow land	Plantations	Water body	Grand Total	Change in Sq.km
LULC 1980	Barren land	39.87	7.55	5.13	0.00	53.68	13.53	119.74	79.89
	Built-up land	2.56	41.57	2.42	0.00	42.14	1.42	90.12	48.54
	Coastal wetland	12.81	1.57	22.07	0.00	12.24	9.97	58.66	36.59
	Fallow land	0.43	0.71	0.00	3.13	16.37	0.57	21.21	18.08
	Plantations	93.54	62.93	10.96	13.95	814.96	64.92	1061.27	246.3
	Water body	7.83	1.00	5.27	0.43	13.95	44.56	73.04	28.48
	Grand Total	157.04	115.32	45.85	17.51	953.35	134.97	1424.04	

Table 7. Temporal variation of interchanged classes in %

	1980 >>1990	1990 >> 2000	2000 >> 2010	2010 >> 2020	1980 >> 2020
BL>>BL	0.21	3.4	2.76	2.77	2.8
BL>>BUL	0.11	0.35	1.08	0.28	0.53
BL>>CW	0.65	0.24	0.41	0.32	0.36
BL>>FL	0.15	0.12	0.06	0	0
BL>>PL	1.29	3.75	6.43	4.61	3.77
BL>>WB	0.18	0.83	0.61	1.11	0.95
BUL>>BL	0.01	0.21	0.56	0.89	0.18
BUL>>BUL	1.85	2.68	3.91	4.75	2.92
BUL>>CW	0.1	0.14	0.19	0.02	0.17
BUL>>FL	0	0.05	0.01	0.01	0
BUL>>PL	0.59	3.15	2.7	4.68	2.96
BUL>>WB	1.07	0.09	0.1	0.25	0.1
CW>>BL	0.03	0.43	0.53	0.92	0.9
CW>>BUL	6.92	0.08	0.04	0.12	0.11
CW>>CW	3.25	1.26	1.65	1.59	1.55
CW>>FL	0	0	0	0	0
CW>>PL	0.04	1.8	0.59	1.09	0.86
CW>>WB	0.12	0.59	0.25	0.71	0.7
FL>>BL	0.04	0.01	0	0.08	0.03
FL>>BUL	0.21	0.03	0.17	0.03	0.05
FL>>CW	0	0	0	0	0
FL>>FL	1.98	0.09	0.03	0.41	0.22
FL>>PL	0.06	1.3	1.18	2.56	1.15
FL>>WB	0.32	0.06	0	0.1	0.04
PL>>BL	3.42	6.46	4.82	5.63	6.57
PL>>BUL	1.77	4.26	5.17	2.84	4.42
PL>>CW	1.27	1.08	1.58	0.99	0.77
PL>>FL	65.3	1.07	2.92	0.81	0.98
PL>>PL	1.63	59.3	54.6	53	57.2
PL>>WB	0.75	2.07	1.27	4.59	4.56
WB>>BL	0.05	0.95	0.61	0.74	0.55
WB>>BUL	0.61	0.08	0.21	0.07	0.07
WB>>CW	0.01	0.36	0.59	0.29	0.37
WB>>FL	3.15	0.05	0.15	0	0.03
WB>>PL	2.83	0.97	2.19	1	0.98
WB>>WB	0.21	2.7	2.57	2.72	3.13

5. Conclusions

In conclusion, the comprehensive analysis of Land Use and Land Cover (LULC) changes in the southeast coast of India, spanning from 1980 to 2020, has provided valuable insights into the dynamic transformations in the region. The dominance of plantation in 1980 gradually decreased over the decades, giving way to changes such as an increase in built-up areas and a rise in barren land. The study highlights the vulnerability of coastal regions to various factors, including natural hazards and human activities, leading to shifts in LULC classes. The validation of LULC classification maps through overall accuracy assessment and Kappa statistics demonstrated the reliability of the results, with accuracy exceeding 75% for all selected years. The temporal differences in each class area, as well as the change rates, underscore the ongoing shifts in land use patterns. The conversion of plantation land into barren and built-up areas, as well as the afforestation activities observed in barren lands, reflects the intricate interplay of natural and anthropogenic factors shaping the coastal landscape. The study emphasizes the importance of continuous monitoring and assessment of LULC changes, especially in vulnerable coastal regions. Such insights are crucial for informed decision-making in sustainable development, urban planning, and land management. Additionally, the observed impact of natural hazards on the economy and livelihoods of coastal communities underscores the need for adaptive strategies and resilient development practices in the face of environmental challenges.

The findings emphasize the need for sustainable development planning in coastal regions. Balancing economic activities, environmental conservation, and community resilience is crucial to mitigate the adverse impacts of LULC changes. Given the susceptibility of coastal areas to natural hazards, enhanced disaster preparedness measures should be implemented. Early warning systems, infrastructure resilience, and community awareness programs can contribute to minimizing the impact of cyclones and storm surges. Recognizing the impact of LULC changes on vegetation cover, targeted afforestation initiatives should be encouraged. Replanting barren lands can enhance ecosystem services, prevent soil erosion, and contribute to biodiversity conservation. In light of the economic challenges faced by coastal communities due to natural hazards, community engagement programs should be initiated. These programs can focus on livelihood diversification, alternative income sources, and sustainable practices to enhance community resilience. The study underscores the importance of continuous monitoring of LULC changes. Regular updates using remote sensing and GIS technologies will provide essential data for adaptive management strategies and informed decision-making. In conclusion, the comprehensive analysis of LULC changes provides valuable insights for policymakers, researchers, and local communities, guiding efforts toward sustainable development and resilience in the face of environmental challenges.

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