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Abstract
The dynamic nature of Land Use and Land Cover (LULC) patterns is a critical indicator of environmental and socioeconomic transformations. This study investigated LULC changes in the Kanyakumari district, Tamil Nadu, over two decades, from 2004 to 2024, using satellite remote sensing data and GIS techniques. Landsat 5, 8, and 9 data were used to analyze and identify shifts in vegetation, settlement, barren land, saltpans, water bodies, and beach sands. The features were selected using supervised classification with the Maximum Likelihood procedure and the

accuracy was measured using metrics such as overall accuracy and the kappa coefficient, which ensured the reliability of the results. The accuracy rates were consistently over 94%. The findings show that the settlement areas have increased from 313.94 km² in 2004 to 357.84 km² in 2024, while the areas of vegetation and saltpan have been steadily decreasing. This trend highlights how factors such as population growth, urban development, and climate change affect land resources. Using geospatial tools to monitor land use and land cover changes has provided crucial insights into sustainable land management and planning. This study emphasises the importance of taking proactive policy steps to tackle land degradation and support balanced growth in the area.

Keywords: Land Use/ Land Cover, Landsat, Maximum Likelihood Classification, Kanyakumari, Environmental Management and Remote Sensing.

Introduction

Land use refers to how people utilise land for various purposes, with a focus on its socioeconomic value, whereas land cover refers to everything on the earth's surface, such as water bodies, forests, and farmland (Raxana and Venkateswaran, 2024; Vijay and Varija, 2024). In recent years, the Kanyakumari district in Tamil Nadu, southern India, has continuously experienced major shifts in land use and land cover, mainly because of anthropogenic influences (R J et al., 2025) and the interplay of both marine and land influences. Human societies have significantly impacted land use and land cover by the flourishing industrial revolution, which has amplified the number of anthropogenic activities globally and regionally (Bagaria et al., 2021; Castro J et al., 2021; S. Kaliraj et al., 2017; Murali Krishna and Sahithi, 2023). Additionally, rapid population growth plays a big role in changing land use and cover. As the population grows, the urge in resource exploitation and infrastructural development leads to exploitation of lot of agricultural and dry land being transformed into built environments (Karan et al., 2024).

Changes on the earth's surface are effectively traceable using remote sensing data because of their strong capabilities in recording temporal, areal, and spectral details. Remote sensing and Geographic Information Systems (GIS) are being widely used to provide more detailed information about land cover (P. Arulbalaji and Gurugnanam, 2014; Nijagunappa et al., 2007). The shifts in land use and land cover (LULC) are observed through satellite images mapped by GIS for specific areas at specific times (Aran Castro A J Kumar, S, 2021; Arulbalaji and Gurugnanam, 2014). The IRS P6 LISS IV MX satellite is particularly effective for tracking land use and cover (Bagyaraj et al., 2014). GIS can assess concurrent parameters in mapping-related investigations(Gurugnanam et al., 2008) and is a valuable tool for mapping spatial variations (Phaisonreng Kom et al., 2023) (Kom et al., 2021) (Arulbalaji. P and Gurugnanam. B, 2016). Through supervised classification, changes in LULC are detected with high accuracy (Srivastava and Chinnasamy, 2021). The kappa coefficient and error matrix are popular quantifiers used to assess the accuracy of image classification in the analysis of land use and land cover within an area (Anand et al., 2024).

Although changes in land use and land cover are dynamic, continuous monitoring of these changes helps formulate various policies that aid in predicting future trends. Integrating this change monitoring with the remote sensing techniques provides multiple insights into local and regional aspects. The main objective of this study was to work with the maximum likelihood supervised classification technique (Khanday and Sujatha, 2021; Thangavelu A et al., 2021; Theenadhayalayan et al., 2009) using remote sensing and GIS methods to determine the land use land cover change in the Kanyakumari district over the past three decades, from 2004, 2014, and 2024.

Study Area

Kanyakumari is the southernmost coastal district of peninsular India, located in the state of Tamil Nadu, with the coordinates 77° 04′ 30″ to 77° 36′ 0″E and 8° 15′ 0″ to 8° 31′ 30″N, respectively (Fig. 1). It has one of the most densely populated coasts among the districts in the state of India (Natesan and Parthasarathy, 2010).The coastal area features well-developed drainage systems, comprising rivers, streams and water bodies (S Kaliraj et al., 2017). The main rivers, Thamirabarani, Valliyar, and Pazhayar, originate in the Western Ghats and flow southward, creating various alluvial and coastal landforms at their mouths. The geological composition of the coastal landscape comprises crystalline rocks, Late Quaternary deposits of clay, sand and sandy materials, a thick layer of laterite soil, and a few rocky outcrops (Kaliraj et al., 2017). In the study area, the nearshore features such as sandy beaches, dune complexes, vegetation, wetlands, and shallow marshes are frequently regulated by physical, climatic, and socioeconomic factors (Aran Castro A J Kumar R S, 2021). The total geographical area is 1672 km². The climatic conditions of Kanyakumari are moderate due to the influence of Southwest monsoon and Northeast monsoon currents of air, the proximity of the sea, and the breathtaking altitude of the Western Ghats, which majorly influence the district's climate (George et al., 2023). The average temperature in the coastal region is 24°C, with a maximum temperature of 34°C (Veeran et al., 2024). The normal yearly precipitation over the district fluctuates from 826 mm to 1456 mm.

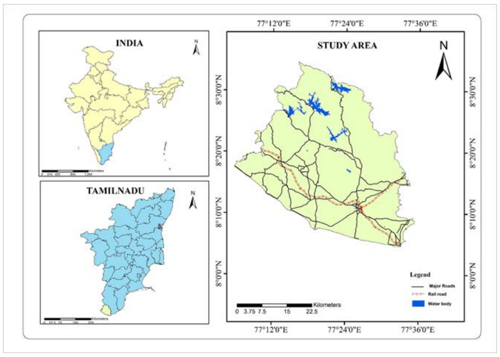


Figure 1 Study Area - Kanyakumari District

Methodology

The satellite images were obtained from the United States Geological Earth Explorer (USGS) Earth Explorer portal for the analysis of the Land Use and Land Cover of the study region (Grace et al., 2025; Kebede and Professur, 2023). Landsat 5, 8, and 9 images were collected for 2004, 2014, and 2024 to analyse changes over the past two decades (Table 1).

Table 1 Details of the Selected Satellite Data

Satellite image	Sensor	Resolution	Date of acquisition
Landsat 5	TM	30	25/02/2004
Landsat 8	OLI/TIRS	30	04/02/2014
Landsat 9	OLI/TIRS	30	27/03/2024

The satellite images were then layer stacked to create a true colour composite (TCC) by combining the red, green, and blue bands, and the false colour composite (FCC) was created by combining the green, red, and infrared bands for a detailed and accurate extraction of the features (Raxana and Venkateswaran, 2024). The training samples are created for each feature in the satellite image, and through Maximum Likelihood classification, the features are classified with the aid of ArcGIS software (Fig. 2). Then, the errors are manually corrected to achieve greater accuracy (Sam and Balasubramanian, 2023). The classified features in this region include waterbodies, vegetation, settlements, barren land, saltpan, and beach sand.

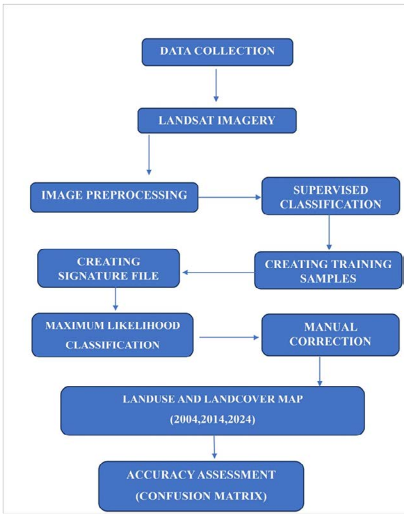


Figure 2 Methodology for LULC

Accuracy Assessment

Accuracy assessment is crucial for ensuring consistency in the classified LULC results (Nath et al., 2023; Sam and Balasubramanian, 2023). The most effective way to assess accuracy is through an error matrix. Accuracy was assessed using four types of evaluations: overall accuracy, user accuracy, producer accuracy, and Kappa statistics (Olusoga et al., 2024). The equations to calculate the accuracy of the classified LULC are as follows:

Producer's Accuracy

The accurate classification of the point in that category is defined as the producer's accuracy. It is calculated using the given formula, Correctly Classified Point (diagonal) = Producer's accuracy/Sum of Classified Points (Sum of Column) x 100

User's Accuracy

The classified pixel on the image correctly represents the class on the ground, which is the user's accuracy. It is calculated as follows:

Correctly Classified Point (diagonal) = User's accuracy/Sum of Classified Points (Sum of row) x 100

Overall's Accuracy

Overall accuracy is based on the accuracy of all the classes. It calculates the pixels that are correctly classified in all the classes. The formula given below calculates the overall accuracy.

Sum of the diagonale elements = overall Accuracy/ Total number of reference Points x 100

Kappa Coefficient

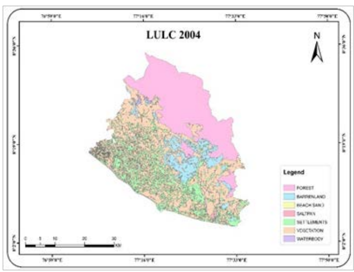
The kappa coefficient is a percentage measure between two features concerning all the error matrix components. Concerning the error matrix, the kappa analysis is well-defined as follows:

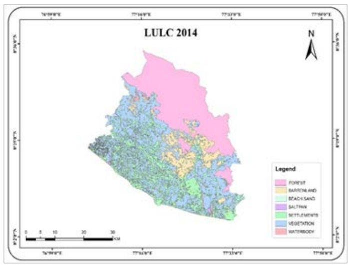
(TS x TCS) - Σ (column Total x Row Total)

Kappa Coefficient/ x 100 $(\text{Total Sample})^2$ - (column Total x Row Total)

Result and Discussion

The classes classified for 2004, 2014, and 2024 were based on the NRSC classification of Land Use and Land Cover. Spatial and temporal changes in this region are shown in Figure 3. The changes from 2004 to 2014 are listed in Table 2, and Table 3 shows the changes in LULC features from 2014 to 2024.





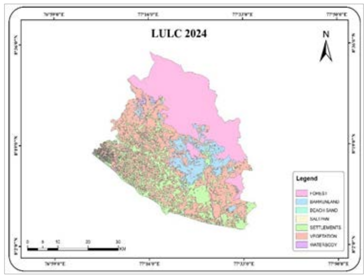


Figure 3 Landuse and Landcover 2004, 2014 & 2024

Barren Land

Barren land refers to land that is unproductive or unsuitable for farming or vegetation due to various factors. This can include land that is infertile, arid, eroded, or has rocky terrain (Castro et al., 2021). In 2004, the barren land occupied 154.59 km^2 in this region. During 2014, it declined by 1.16 km^2. However, during 2024, the area increased to 164.08 km^2, resulting in a 10.65 km^2 increase due to low rainfall, which contributed to the loss of vegetation and made the land more barren.

Beach Sand

Beach sand is composed of loose rock, mineral,s and biological materials found along river, sea, and ocean shorelines. It is mainly composed of quartz and other minerals that are shaped and carried by currents, tides and waves. Beach sand covered 3.16 km^2 of the study region in 2004. Due to human activities such as construction, sand mining and coastal development, the area had shriveled to 2.95 km^2 by 2024.

Saltpan

The backwaters and estuaries are home to the majority of saltpans in the study region. The saltpan's area decreased from 3.15 km^2 in 2004 to 2.99 km^2 in

2014 and then to 2.67 km² in 2024. Climate change, water management techniques and human activities such as pollution and land development in this area are all contributing to the decline of saltpans.

Settlement

A settlement is a city, town, village, or other group of buildings where people live and carry out their daily activities. A settlement generally includes roads, enclosures, field systems, boundary walls and ditches, ponds, parks and woods, wind and watermills, manor buildings, moats, and churches (Raxana and Venkateswaran, 2024). In 2004, the study area's settlement was 313.94 km². In 2014, settlement occupied 331.06 km² of the study area, representing a 5.4% increase. The area covered in 2024 is 357.84 km², which is an 8% increase from 2014 to 2024. Population growth, economic development, increased infrastructure, available land, government plans, and breakthroughs in construction technology contributed to the increase in settlements. Also, according to the 2011 census, the population density of the Kanyakumari district's coastal area is 1005 people per square kilometre (Castro J et al., 2021).

Vegetation

The greenery that is present above the ground's surface is called vegetation. In 2004, it covered 649.36 km² of the study area. The vegetation in the study area covered 630.07 km² in 2014, but was reduced to 594.40 km² in 2024, showing a declining trend. Every year, the amount of vegetation decreases owing to factors such as logging, urbanisation, and deforestation. The loss of vegetation cover in this area has also been caused by climatic factors, including rising temperatures, shifting rainfall patterns, and unsustainable farming practices.

Waterbody

Three significant rivers, namely Thamirabarani, Pazhaiyar, and Valliyar, flow through the study area, with their major and minor tributaries. These rivers play a vital role in the main sources of agricultural activity, as plantations and croplands are concentrated along their bank. In 2004, the area covered by water was 21.29 km², which increased to 24.79 km² by 2014 and then decreased to 23.36 km² by 2024. The increase and decrease in water bodies over the years were influenced by factors such as climate variability, human activities, and rainfall during this period.

Table 2 LULC Shift between 2004 and 2014

LULC	Area 2004 (km²)	Area 2014 (km²)	Area change (2004-2014)	Percentage change (%)
Barren land	154.59	153.43	-1.16	-0.75%
Beach Sand	3.16	3.16	0	0%
Saltpan	3.15	2.99	-0.16	-5.07%
Settlement	313.94	331.06	17.12	5.45%
Vegetation	649.36	630.07	-19.29	-2.97%
Waterbody	21.29	24.79	3.5	16.43%

Table 3 LULC Shift from 2014 to 2024

LULC	Area 2014 (km²)	Area 2024 (km²)	Area change (2014-2024)	Percentage change (%)
Barren land	153.43	164.08	10.65	6.94%
Beach sand	3.16	2.95	-0.21	-6.64%
Saltpan	2.99	2.67	-0.32	-10.70%
Settlement	331.06	357.84	26.78	8.08%
Vegetation	630.07	594.40	-35.67	-5.66%
Waterbody	24.79	23.36	-1.43	-5.76%

Accuracy Assessment

Ground control points were used to determine the accuracy of the LULC analysis for each feature classified in 2004, 2014, and 2024. The producer and user accuracy of each class are presented in Table 4. The overall accuracy and kappa coefficient for 2004, 2014, and 2024 are 95.63% & 93.22, 94.50% & 91.55, and 96.35% & 94.53, respectively.

Table 4 Producer's Accuracy, User's Accuracy, Overall Accuracy, and Kappa Coefficient of 2004, 2014, and 2024

Accuracy types	LULC	2004	2014	2024
Producer Accuracy	Barren land	100.0	100.0	97.14
	Beach sand	100.0	100.0	100.0
	Saltpan	100.0	100.0	100.0
	Settlement	95.58	92.85	100.0
	Vegetation	94.55	93.70	94.16
	Waterbody	90.0	90.0	90.90
User Accuracy	Barren land	91.17	90.90	94.44
	Beach sand	90.0	100.0	100.0
	Saltpan	100.0	100.0	100.0
	Settlement	94.20	90.27	91.10
	Vegetation	97.88	97.10	99.23
	Waterbody	90.0	90.0	100
Overall Accuracy		95.63	94.50	96.35
Kappa coefficient		93.22	91.55	94.53

Conclusion

The LULC changes in the Kanyakumari district from 2004 to 2024 were explored in this study using Landsat satellite data and GIS techniques. This study concludes that the total area of vegetation decreased from 649.36 km² to 594.40 km², representing a loss of 54.96 km² of vegetative area between 2004 and 2024. Additionally, the settlement region expanded from 313.94 km² to 357.84 km², representing a 43.9 km² increase during the study period. The vegetation area has diminished as a portion has been transformed into the Settlement Area. During this period, the area of coverage of the saltpan also decreased from 3.15 km² to 2.67 km², whereas the region covered by water bodies increased by 2.07 km². Articulating specific environmental shielding regulations through periodic monitoring assessments by policymakers may help conserve depleting water bodies and vegetation, which, in turn, facilitates changes in local and regional climatic conditions.

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