GEOGRAPHICAL ANALYSIS

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Land Use Land Cover Mapping Along Tirunelveli Coast, Tamil Nadu, Using Open Source Software (QGIS)

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Abstract

Indian coastal zones have diverse ecological and geomorphological features; however, they are recurrently influenced by anthropogenic activities and natural disturbances. Therefore, understanding coastal land use and land cover features is essential for protecting these zones. Remote sensing is a crucial tool for identifying and quantifying coastal features with synoptic coverage. The present study focuses on land use and land cover mapping along the Tirunelveli coast using QGIS and LISS III datasets. The results revealed the following land cover classifications in the Tirunelveli coastal area: barren land (17.083 km^2), built-up area (26.096 km^2), dense vegetation (24.167 km^2), industrial discharge (3.186 km^2), industrial waste (1.716 km^2), low-density vegetation (36.818 km^2), sand dune plants (18.568 km^2), sandy beach area (32.710 km^2), scrub area (14.426 km^2), Teri sand area (20.553 km^2), and water bodies (including freshwater and seawater), covering 305.068 km^2. The overall classification accuracy was 86.85%. This study provides valuable insights into the coastal regulation zone in the Tirunelveli coastal area and may contribute to future coastal conservation research.

Keywords: Tirunelveli coast; Land use land cover; QGIS; LISS III; Conservation

1 Introduction

The coastal zone of Tamil Nadu is endowed with diverse landscapes, including sandy beaches, beach ridges, backwaters, estuaries, intertidal mud and sand flats, dunes, cliffs, beach rocks, deltas, lagoons, mangrove forests, and coral reef ecosystems. In particular, the southern coast of Tamil Nadu contains rich deposits of rare minerals such as ilmenite, garnet, sillimanite, pyroxenes, amphiboles, zircon, rutile, monazite, kyan-ite, and, less frequently, spinel, tourmaline, epidote, apatite, and staurolite[1]. Understanding the quantity and vulnerability of coastal features is essential for coastal conservation and management. remote sensing-based coastal mapping is a reliable tool for accurately quantifying coastal landform features, analyzing changes over past decades, making future predictions, and aiding in conservation management action plans. Remote Sensing (RS) and Geographical Information System (GIS) technologies have provided

significant advantages in geomorphologic investigations and have proven to be extremely useful for coastal landform mapping. The advantages of remote sensing in coastal landform mapping include synoptic coverage, high resolution, multispectral capabilities, and cost-effectiveness. Space technology, with its ability to provide large-scale information on a repetitive basis, has been highly effective in identifying and monitoring various coastal features and in planning the development of coastal areas[2]. Remote Sensing and GIS are also invaluable for developing coastal databases, analyzing them in an integrated manner, and deriving management action plans. Additionally, GIS can be effectively used for the conservation of coastal zones. While conventional maps are useful and provide up-to-date information, remote sensing techniques offer a deeper understanding of landform resources, evaluation of land and water, planning methods, environmental conservation, and management practices[3].

GIS has been developed over several decades, resulting in the creation of successful proprietary software packages such as the ESRI ArcGIS suite, Erdas Imagine (Leica Geosystems Inc.), ENVI (Environmental Visualization), PCI Geomatica, MapInfo (Pitney Bowes Software), and TNTmips. These widely used tools have made GIS software more accessible and cost-effective. In recent years, there has been significant growth in open-source geospatial software, particularly QGIS. QGIS (Quantum GIS) is a user-friendly, open-source geographic information system (GIS) designed for modeling and decision support, with a particular emphasis on coastal mapping in developing countries. It serves as a desktop GIS solution that competes with traditionally monopolized proprietary software while offering a fresh approach. QGIS is compatible with major operating systems such as Windows, Linux, Android, and macOS. Built on the robust, cross-platform Qt C++ development framework, it enables users to work without the burden of costly licensing fees or restrictive terms. This flexibility in deploying desktop GIS solutions fosters greater community participation in coastal science across the globe[4].

From a technical perspective, QGIS is considered one of the most promising free desktop GIS platforms because it (i) provides an effective interface to the often-complex GRASS GIS, SAGA GIS, and the Orfeo Toolbox, and (ii) offers extensive customization options (e.g., Python for scripting). Currently, the software boasts one of the largest FOSS GIS user communities[5]. The features of QGIS are easy to use, allowing for the quick creation of simple maps. However, more complex functions, such as thematic mapping and querying, require additional time and effort to learn and apply successfully. Surprisingly, some basic features that GIS users often expect—such as text or graphic annotations, custom labelling, and image manipulation (clipping) or high-resolution image export—are not available. Nevertheless, for a free program, QGIS is remarkably sophisticated and offers

many valuable GIS tools. In light of these factors, the present study aims to evaluate the effectiveness of QGIS in coastal zone mapping. The study was conducted with the following objectives:

1. To analyze the land use and land cover patterns along the Tirunelveli coast;
2. To quantify the coastal geomorphological features present along the Tirunelveli coast.

2 Materials and Methods

Study area

The Tirunelveli coast is located in the southern part of Tamil Nadu, situated between the longitudes of 78° 7′ 30′′ E and 77° 35′ 30′′ E, and latitudes of 8° 27′ 30′′ N and 8° 2′ 30′′ N (Figure 1). The coast stretches from Kayamozhi to Karungulam village, covering a distance of 48.9 km and oriented in a NE-SW to SW direction. The district receives rainfall from both the southwest and northeast monsoons, with the northeast monsoon being the primary contributor. The average annual rainfall in the district is 879 mm. The relative humidity is typically ranges between 79% and 84%. The mean minimum temperature is 22.9°C, while the mean maximum daily temperature is 33.5°C[6]. Onshore coastal sand mining is actively practiced along these coasts. The inland Teri (red-colored) sand dunes and beach areas are rich in mineral deposits. Currently, the beach sands are extracted and processed physically for export, with 100% of the output being exported without any value addition[7].

Satellite data processing

Cloud-free multispectral satellite data from IRS P6 (Resourcesat-1) LISS III 2008 was selected for the classification work and to account for the geomorphological features. The dataset consists of four spectral band layers: green (0.52–0.59 μm), red (0.62–0.68 μm), near-infrared (NIR) (0.77–0.86 μm), and short-wave infrared (SWIR) (1.55–1.70 μm). QGIS (Quantum GIS) version 2.0.1 Dufour with the necessary tools and plug-ins were used for image processing and interpretation in this study. The selected image was geometrically corrected (using geographic lat/long, WGS 84) with the Survey of India (SOI) toposheet, 1969 (Index No. 58 1/L), incorporating a sufficient number of ground control points (GCPs). The RMS error (root mean square) was reduced to less than 1 pixel. Radiometric correction was applied to each layer using the raster calculator tool. Reflectance values were obtained from the product handbook[8]. Image enhancement, including contrast stretching and linear stretching, was applied to each layer to improve classification efficiency. A shoreline vector layer was created, followed by the generation of a buffer zone with a cross-section of 1 km. The region of interest was then subset using the shoreline buffer.
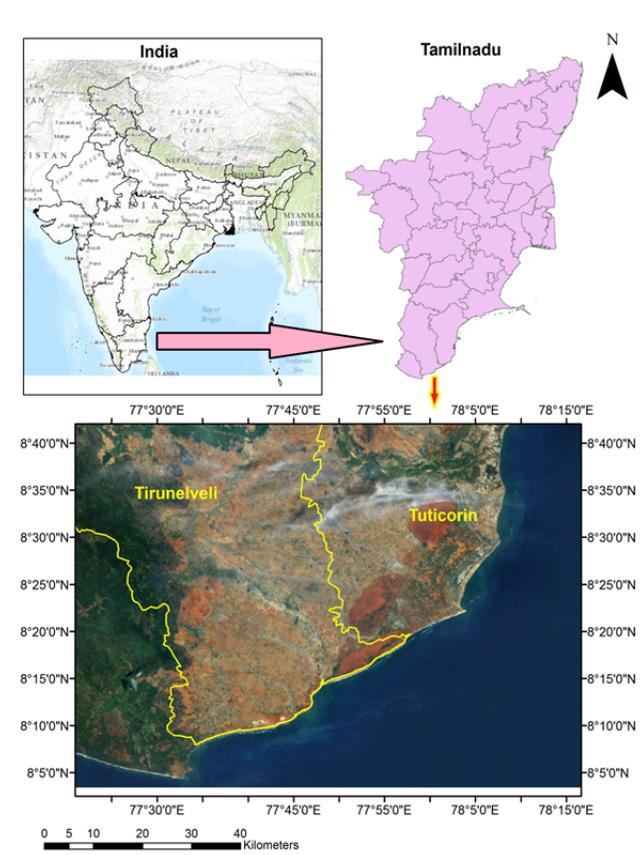
Fig. 1. Tirunelveli coastal study area southeast of India

Fig. 2. Flow chart of Tirunvelveli coast land use and land cover mapping using QGIS

The classification was performed using maximum likelihood classification with the semi-automatic classification plug-in (version 2.2), as described by Congedo[9]. The classification process steps are outlined in the classification flow chart (Figure 2). The accuracy error matrix and classification report were generated to assess the overall accuracy of the maps. The classification report summarizes the area coverage of each class, and the error matrix provides the kappa value for the classified pixels.

3 Results

The present study focused on quantifying the coastal features along the Tirunelveli coast using the IRS LISS III 2008 image. The image processing and interpretation were conducted using the free and open-source software QGIS 2.0.1. To extract the area of interest, the shoreline was digitized (Figure 3), and a buffer zone (1 km radius) was created using the shoreline vector (Figure 4). The study region was then extracted based on the buffer zone extents. Supervised classification was performed using the semi-automatic classification plug-in (version 2.2). The output thematic map was generated at a 1:175,000 scale (Figure 5).
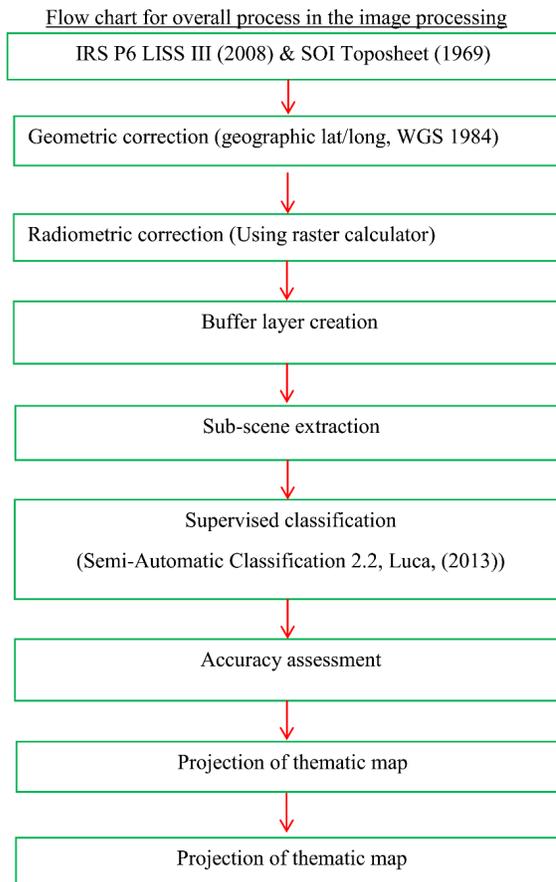

Fig. 3. Map showing the digitized shoreline

Fig. 4. Creation of buffer zone
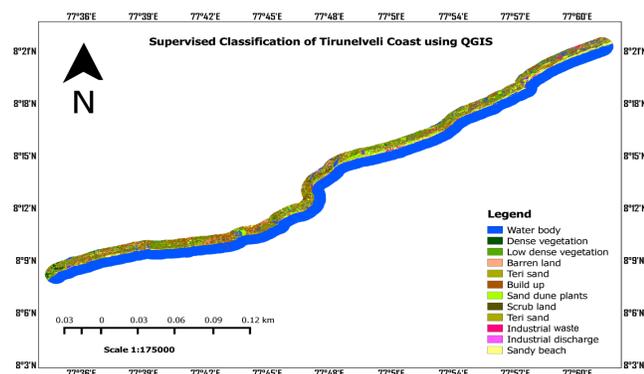
Fig. 5. Final classified map depicting the land use and land cover pattern along the Tirunelveli coast

Table 1. Land use land cover features along the Tirunelveli coastal zone

Features	Area (Km^2)	Percentage (%)
Barren land	17.083	3.4
Built up area	26.096	5.2
Dense vegetation	24.167	4.8
Industrial discharge	3.186	0.6
Industrial waste	1.716	0.3
Low dense vegetation	36.818	7.4
Sand dune plants	18.568	3.7
Sandy beach	32.710	6.6
Scrub	14.426	2.9
Teri sand	20.553	4.2
Water body	305.068	60.9
Total	**500.393**	**100.0**

Table 2. Percentage of commission and omission errors and estimated kappa value of accuracy assessment

Features	% Commission	% Omission	Estimated Kappa
Barren land	6.2500	7.3530	0.9345
Built up area	23.8677	15.8299	0.7577
Dense vegetation	25.4006	4.3478	0.7429
Industrial discharge	24.3243	12.5557	0.7496
Industrial waste	28.5714	27.3333	0.7265
Low dense vegetation	19.5003	19.6311	0.7994
Sand dune plants	31.5035	25.2142	0.5791
Sandy beach	30.3142	35.7696	0.6904
Scrub	23.4254	20.1752	0.7567
Teri sand	24.4451	5.9135	0.7530
Water body	9.3939	22.0513	0.9040
Average	**22.4542**	**17.8341**	**0.7631**

After performing the classification, area estimation was calculated using embedded tools in the plug-in (Table 1). The image classification was based on the user's field knowledge. Finally, an accuracy assessment was conducted, and an error table (commission, omission, and Kappa values) was generated for the respective image (Table 2). The coastal features were classified into eleven categories: barren land, built-up area, low-density vegetation, dense vegetation, industrial discharge, industrial waste, sand dune plants, sandy beach, scrub, Teri sand, and water body.

The estimated areas for the various land features are as follows: barren land (17.083 km^2), built-up area (26.096 km^2), dense vegetation (24.167 km^2), industrial discharge (3.186 km^2), industrial waste (1.716 km^2), low-density vegetation (36.818 km^2), sand dune plants (18.568 km^2), sandy beach area (32.710 km^2), scrub area (14.426 km^2), Teri sand area (20.553 km^2), and water body (including freshwater and seawater) area (305.068 km^2). The accuracy of each classified feature, as well as the overall classification, was assessed, with commission errors, omission errors, and Kappa values reported for barren land (6.25, 7.353, and 0.9345), built-up area (23.8677, 15.8299, and 0.7577), dense vegetation (25.4006, 4.3478, and 0.7429), industrial discharge (24.3243,

12.5557, and 0.7496), industrial waste (28.5714, 27.3333, and 0.7265), low-density vegetation (19.5003, 19.6311, and 0.7994), sand dune plants (31.5035, 25.2142, and 0.5791), sandy beach (30.3142, 35.7696, and 0.6904), scrub (23.4254, 20.1752, and 0.7567), Teri sand (24.4451, 5.9135, and 0.7530), and water body (9.3939, 22.0513, and 0.9040).

The Kappa values indicate that barren land features and water bodies had higher accuracy and were well-classified (0.9345 and 0.9040, respectively). The signature patterns for industrial discharge and industrial waste, sandy beaches, and sand dunes were similar, resulting in higher commission and omission errors for those features. The accuracy, in decreasing order, was as follows: low-density vegetation (0.79), built-up area (0.7577), scrub (0.7567), Teri sand (0.7530), industrial discharge (0.7496), dense vegetation

(0.7429), industrial waste (0.7265), sandy beach (0.6904), and sand dune vegetation (0.5791).

Low-density vegetation was significantly present in the area, while dense vegetation was relatively sparse. The built-up area was well-distributed in the coastal region, showing an expansion trend towards the landward side. Sandy beaches and sand dune vegetation were notably present along the coastal region. Teri sands were classified as a separate feature due to their abundant presence in the region. Renewable and non-renewable natural resources, as well as the discharge of waste effluents and municipal sewage, were observed, and the area was classified as industrial discharge and waste (dumping of solid waste). The overall classification was found to be accurate, with a Kappa value of 0.7631, and the classification accuracy was 86.85%.

4 Discussion

Coastal zones are often influenced by both terrestrial and marine components, resulting in the formation of unique landforms and ecosystems. Knowledge of the coastline forms the basis for measuring and characterizing land and water resources of a given region. Additionally, change detection is essential for safe navigation, resource management, environmental protection, and sustainable coastal development and planning[10,11]. The sand-dune vegetation is well-distributed along the coastal region of the Tirunelveli coast. One of the most active processes on the Visakhapatnam-Bhimunipatnam coast is the formation of coastal sand dunes. A distinctive feature of these dunes is the vegetative cover. Dunes that are further inland tend to have more vegetation than those closer to the sea[12]. Evaluating the spectral signature of sand dune vegetation and sandy beaches can be challenging, as their signatures are quite similar and often confusing. This similarity increases the percentage of commission and omission errors. When evaluating land cover classification results, it is important to consider how cover types are differentiated. The most significant misclassification errors occur between the improved and poor pasture categories, as these are often difficult to distinguish unambiguously in the field. Consequently, the lower classification accuracy may stem from issues in defining the training and test data. Furthermore, as classification accuracy varies with the time of data capture, some of the challenges likely arise from the nature of the image data itself[13].

The accuracy estimation of a thematic map serves as a valuable and objective tool for evaluating its reliability. Regarding the accuracy of various categories, barren land was classified with high accuracy, followed by water bodies (both above 90%). The built-up area, dense vegetation cover, low-density vegetation, industrial discharge, industrial waste, terri sands, and scrub were classified as above average (70%–90%). Sandy beaches and sand dune plants were classified as average, with an accuracy range of 55%–70%, due to misclassification

of similar signature patterns.

The barren land feature was clearly observed in the image with a unique pattern of spectral signature, identified by a sufficient number of polygons (ROIs). It demonstrated good accuracy, with a 6.25% commission error and 7.353% omission error, yielding a kappa value of 0.9345. The low-density vegetation was significantly present in the area, while dense vegetation was relatively sparse. The built-up area appeared well-distributed in the coastal region, showing an expansion trend toward the landward side. This feature was easy to identify in the FCC imagery, and automated polygons could be created in this region with unique spectral signatures. Although it was classified as above average (kappa = 0.7577), this classification was still relatively accurate. Sandy beaches and sand dune vegetation were observed along the coastal region as well. Teri sands were classified as a separate feature due to their abundant presence in the region, which made them significant in terms of spectral signature. Because of this factor, the feature was classified as above average (kappa = 0.753), with minimal misclassification (omission error = 5.91%).

Renewable and non-renewable natural resources, discharge of waste effluents, municipal sewage, and the development of various industrial effluents were observed and classified in the area as industrial discharge and waste. Water bodies, occupying more than half of the area (60.9%) and exhibiting a unique spectral signature, were classified with a sufficient number of polygons (ROIs). As a result, the commission error was 9.39%, with a kappa value of 0.90. The final output map was projected with 22.45% commission error and 17.83% omission error. The overall classification was found to be accurate, with a kappa value of 0.7631. The user's logic and field knowledge would further improve the result.

The present study observed that the semi-automatic classification plug-in in QGIS has the ability to effectively identify and collate similar types of pixels. The study concludes that QGIS is highly effective for coastal zone mapping studies and appropriate for remote sensing and GIS-based coastal conservation management.

5 Conclusions

The present study classified coastal features into eleven categories: barren land, built-up areas, dense vegetation, industrial discharge, industrial waste, low-density vegetation, sand dunes, sandy beaches, scrub, teri sand, and water bodies. Among these, low-density vegetation was the most prevalent, excluding water bodies. Other prominent features included sandy beaches, sand dunes, built-up areas, scrub, and dense vegetation. Teri sand was also observed in considerable amounts, suggesting the area's mineral richness. Built-up areas were well-distributed across the region. Industrial discharge and waste effluents were estimated to be minimal, although further data is needed for a more comprehensive

analysis of their presence. The accuracy assessment of individual features highlighted the efficiency of evaluating pixel signatures and grouping features. This study also demonstrated that open-source QGIS software is a valuable tool for remote sensing and GIS-based coastal zone management and conservation, offering reliable and quantifiable information at no cost.

Acknowledgment

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