International Journal of Geography, Geology and Environment

P-ISSN: 2706-7483
E-ISSN: 2706-7491
IJGGE 2024; 6(2): 57-65
www.geojournal.net
Received: 18-07-2024
Accepted: 23-08-2024

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Spatiotemporal analysis of land use/land cover changes and vegetation health in south Andaman district using remote sensing and GIS

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DOI: https://doi.org/10.22271/27067483.2024.v6.i2a.289

Abstract
This study investigates land use/land cover (LULC) changes and vegetation health conditions in the South Andaman District from 2002 to 2014 using remote sensing and GIS techniques. The Landsat 7 ETM+ and Landsat 8 satellite images were analyzed in order to measure variations in eight primary LULC classes. The findings reveal substantial changes in the topography, including considerable declines in mangrove (-6.44%), coral reef (-28.74%), and agricultural land (-19.45%) areas. In contrast, settlements expanded by 48.69% as a result of rising tourism and population growth. The lowest change in the forest cover (-0.60%) was ascribed to successful conservation measures. The study also evaluated the state of vegetation using the Vegetation Condition Index (VCI), Temperature Condition Index (TCI), and Vegetation Health Index (VHI). The indices indicate that vegetation health is generally positive in elevated, forested areas but is negatively affected in locations with human activities. The study emphasizes how the island's ecology has been impacted by development, tourism, population increase, and the 2004 tsunami. In order to address these modifications and foster sustainable growth, an environmental zoning strategy is suggested. Policymakers and environmental planners can gain important insights from this study, which shows how well multi-temporal satellite data can be integrated with vegetation health indices for complete environmental monitoring and management in island ecosystems.

Keywords: Land use/land cover change, vegetation health, remote sensing, GIS, south Andaman island

Introduction
The dynamics of land use and land cover (LULC) change have become a critical area of study in environmental sciences, particularly in the context of rapidly evolving island ecosystems. These changes, driven by both natural processes and anthropogenic activities, have profound implications for biodiversity, ecosystem services, and overall environmental sustainability [1, 2]. In recent decades, the South Andaman District, part of the Andaman and Nicobar Islands in the Bay of Bengal, has experienced significant transformations in its landscape, making it an ideal case study for understanding the complexities of LULC changes in insular environments.

Island ecosystems, characterized by their unique biodiversity and fragile ecological balance, are particularly vulnerable to environmental changes. The Andaman and Nicobar Islands, known for their rich tropical forests, diverse marine life, and distinctive cultural heritage, face mounting pressures from population growth, urbanization, and tourism development [3]. These pressures, combined with natural events such as the devastating 2004 Indian Ocean tsunami, have accelerated the pace of LULC changes, necessitating a comprehensive analysis of these transformations and their impacts.

Remote sensing and Geographic Information Systems (GIS) have emerged as indispensable tools for monitoring and analyzing LULC changes over large spatial and temporal scales. These technologies offer the ability to capture, process, and analyze multispectral satellite imagery, providing researchers with valuable insights into landscape dynamics that would be impractical to obtain through traditional field-based methods alone [4]. In the context of the South Andaman District, previous studies have utilized these techniques to assess LULC changes in specific areas, such as Neil Island [5] and the lower part of South Andaman Island [6], highlighting the efficacy of these methods in island environments.

The assessment of LULC changes is crucial for understanding the environmental consequences of human activities and natural processes. In coastal and island regions, such changes can have far-reaching effects on ecosystems, including mangrove forests, coral reefs, and terrestrial habitats [7-9]. Monitoring these changes is essential for developing effective strategies for sustainable resource management and conservation [10].

In addition to quantifying LULC changes, assessing vegetation health is crucial for understanding the overall ecological condition of an area. Vegetation health indices derived from satellite data, such as the Vegetation Condition Index (VCI), Temperature Condition Index (TCI), and Vegetation Health Index (VHI), provide valuable information about the impact of environmental factors on plant growth and vigor [11-13]. These indices have been successfully applied in various regions to monitor agricultural drought, assess ecosystem health, and evaluate the impacts of climate variability on vegetation [14-16].

The application of vegetation health indices in island ecosystems like South Andaman offers a unique opportunity to examine the interplay between land cover changes and vegetation condition. By combining LULC change analysis with vegetation health assessment, researchers can gain a more comprehensive understanding of the environmental dynamics at play. This integrated approach is particularly relevant in the context of climate change and increasing human pressures on island environments, where vegetation health can serve as an indicator of ecosystem resilience and the effectiveness of conservation efforts.

This study aims to conduct a thorough analysis of land use/land cover changes and vegetation health conditions in the South Andaman District from 2002 to 2014. This research utilizes multi-temporal Landsat satellite imagery analysis and vegetation health indices to quantitatively and qualitatively analyze changes in land use and land cover across various classes. Additionally, it aims to assess the spatial variability of vegetation health in relation to these changes and evaluate the impacts of human activities and natural events on the island's ecosystem. This study aims to showcase the effectiveness of integrating LULC change analysis with vegetation health assessment as a reliable method for monitoring the environment in island ecosystems. The findings will offer valuable insights to support sustainable land management strategies and conservation policies for the South Andaman District.

Study area

The study area for this research is the South Andaman District, one of three districts in the Andaman and Nicobar Islands union territory of India. Located between 10°30' and 12°20' North latitude and 92° and 94° East longitude, it comprises the southern part of the Andaman group of islands. With a total geographical area of 3,106 square kilometers, it is the second largest district in the territory. The district consists of 10 inhabited islands, with South Andaman and Little Andaman being the major ones. Physiographically, the area is characterized by complex topography with elevations up to 470 meters above sea level, including hill ranges, valleys, and coastal plains. The climate is tropical, warm and humid, with two main seasons - summer and rainy. It receives heavy rainfall from both southwest and northeast monsoons, averaging around 3,000 mm annually. More than 65% of the district is covered by tropical rainforests, including evergreen, semi-evergreen and coastal mangrove forests.

The area has rich biodiversity and is home to many endemic species of flora and fauna. Geologically, it is part of an active tectonic zone, comprising sedimentary, igneous and metamorphic rocks. The population as per the 2011 census was 2, 37,586, with Port Blair being the major urban center and district headquarters. The economy is based on agriculture, plantations, fishing, and increasingly, tourism. This unique island ecosystem faces developmental pressures from population growth, urbanization, and tourism activities, making it an important area for studying land use/land cover changes and environmental quality using remote sensing and GIS techniques.

Methodology

This study employed a combination of remote sensing and Geographic Information System (GIS) techniques to assess land use/land cover (LULC) changes and vegetation health conditions in the South Andaman District. The methodology encompassed image acquisition, pre-processing, classification, change detection, and vegetation health index calculation.

Data Acquisition and Pre-processing

Satellite imagery from Landsat 7 Enhanced Thematic Mapper Plus (ETM+) for 2002 and Landsat 8 for 2014 were obtained from the United States Geological Survey (USGS) Earth Explorer platform. These multi-spectral datasets, with a spatial resolution of 30 meters, were selected for their suitability in conducting Level II land-use/land-cover classification. The study involved several pre-processing steps to ensure data quality and comparability. These included radiometric calibration, atmospheric correction using the 6S method, conversion to top of atmosphere (TOA) reflectance, and geometric correction. The digital numbers of the satellite images were converted to at-sensor spectral radiance, and the images were dereferenced to the Universal Transverse Mercator projection system, WGS-84 datum, Zone 46. These steps were implemented to improve the accuracy of surface reflectance values.

LULC classification

A hybrid approach was used for LULC mapping, combining visual interpretation and supervised classification. On-screen digitization was performed in ArcGIS 10.1 to identify major LULC features. The maximum likelihood classification algorithm was used, with 13 LULC classes initially defined. Representative training sites were chosen based on ground truth data and visual interpretation of high-resolution imagery. Post-classification accuracy was assessed using a confusion matrix, and an overall classification accuracy of 85.40% was achieved, meeting the minimum accuracy threshold for reliable LULC mapping. This approach ensures accurate and reliable mapping of LULC features. Change detection was performed by comparing the classified LULC maps of 2002 and 2014 using the post-classification comparison method in ArcGIS 10.1. This approach allowed for the quantification of change information for each LULC class.

Vegetation Health Assessment

To monitor the overall vegetation condition of the South Andaman District, three vegetation health indices were calculated:

1. Vegetation Condition Index (VCI): VCI = 100 * (NDVI - NDVImin) / (NDVImax - NDVImin)
2. Temperature Condition Index (TCI): TCI = 100 * (BTmax - BT) / (BTmax - BTmin)
3. Vegetation Health Index (VHI): VHI = a * VCI + (1 - a) * TCI

Where: NDVI, NDVImax, and NDVImin are the smoothed Normalized Difference Vegetation Index, its absolute maximum and minimum values respectively. BT, BTmax, and BTmin are similar values for Brightness Temperature. A is a coefficient quantifying the share of VCI and TCI contribution in the total vegetation health (set to 0.5 in this study).
These indices were calculated for both 2002 and 2014 images, resulting in six vegetation health maps (VCI, TCI, and VHI for each year). The indices range from 0 (extreme stress) to 100 (favorable condition), with 50 representing average conditions.

Results and Discussion
Combining LULC derived from the temporal satellite images and vegetation health indices, a thorough understanding of the changes in land use and land cover (LULC) and the overall ecological state of the South Andaman District from 2002 to 2014 has been achieved.

Land use/land cover change analysis
Significant changes were observed in different land use and land cover categories in the South Andaman District from 2002 to 2014, as indicated by the analysis of Landsat imagery (Table 1 & Figure 2). The modifications in question demonstrate the intricate relationship between natural phenomena, human actions, and the consequences of the 2004 Indian Ocean tsunami.

Exploring Changes in Forest Cover: In contrast to the worldwide pattern of extensive deforestation in tropical areas [17], our analysis reveals a relatively small decline in forest cover (-0.60%) in the South Andaman District. There was a decrease in the total forested area from 132,077.43 ha in 2002 to 131,281.02 ha in 2014, resulting in a loss of 796.41 ha (Table 1 & Figure 3). The Andaman and Nicobar Islands have successfully implemented strict forest conservation policies and management strategies, resulting in a relatively low rate of deforestation. It is worth mentioning that although the overall forest loss seems to be small, there were instances of deforestation in specific areas, especially near growing settlements and agricultural lands.
The remarkable resilience of the forest cover in South Andaman is especially notable considering the growing population pressures and the aftermath of the devastating 2004 tsunami. The stability observed in the forest suggests that the current practices for managing the forest are quite effective in preserving its extent. It is important to emphasize the ongoing need for monitoring forest quality and fragmentation, as these factors have a significant impact on biodiversity and ecosystem services, even if the overall forest area remains unchanged [18].

Changes in the Mangrove Ecosystem: One of the most alarming findings of this study is the notable decrease in mangrove cover. According to Table 1, there was a decrease in the mangrove area from 13,832.01 ha in 2002 to 12,941.19 ha in 2014, which translates to a reduction of 6.44%. This loss is especially concerning considering the vital ecological and protective roles that mangroves play in coastal ecosystems [19]. There are several factors that have contributed to the decline:

1. The 2004 tsunami had a severe impact on the mangrove forests, causing extensive uprooting and damage [20].
2. The increase in tourism infrastructure and activities in coastal areas has resulted in the clearance of mangroves, as highlighted by Bera, S. 2015 [9].
3. Overexploitation of mangroves for timber and fuel.

The depletion of mangroves not only diminishes the island's inherent protection against storm surges and tsunamis, but also disrupts the habitats where a wide range of marine species reproduce, potentially causing repercussions for local fisheries and biodiversity [21]. The current trend highlights the pressing necessity for focused conservation and restoration initiatives in the South Andaman District.

Coral Reef Degradation
Our analysis uncovers a significant decrease in coral reef cover, with a 28.74% drop from 13,337.82 ha in 2002 to 9,504.72 ha in 2014 (Table 1 & Figure 3). This significant decline in coral reef habitat aligns with the worldwide pattern of coral reef degradation, as observed by [22].

Multiple factors can be attributed to this loss

1. The 2004 tsunami caused significant physical damage, which was particularly noticeable in areas like Wandoor [23].
2. Sedimentation from land-based activities has been found to have detrimental effects on coral reefs. These activities, such as deforestation and agriculture, can lead to an increase in sedimentation, which in turn can smother corals and reduce the amount of light that reaches them [24].
3. The increase in sea surface temperatures and ocean acidification caused by climate change has resulted in coral bleaching events [25].
4. The increase in tourism activities may lead to direct physical damage to reefs, as noted by Lamb *et al.* in 2014 [26].

The alarming decline of coral reef habitat is especially worrisome due to its crucial function in preserving marine biodiversity, safeguarding coastlines, and supporting local livelihoods through fisheries and tourism [27].

Urban Expansion and Settlement Growth: One of the most significant findings of this study is the considerable growth in settlement area. It experienced a 48.69% increase, expanding from 1,861.29 ha in 2002 to 2,767.59 ha in 2014 (Table 1 & Figure 3). This rapid urban expansion is a clear reflection of the widespread urbanization happening in coastal areas around the world [28]. There are several factors that can be attributed to this phenomenon:

1. Population growth and migration from mainland India [29].
2. The need to enhance tourism infrastructure to accommodate the growing number of visitors has been highlighted in recent research Bera, S. 2015 [9].
3. Post-disaster efforts to rebuild and relocate coastal

communities to more secure inland regions.

The urban growth in South Andaman is clearly visible in and around Port Blair, which serves as the main urban center of the district. The expansion has important implications for land use planning, infrastructure development, and natural resource management.

Agricultural Land Dynamics

In contrast to the prevailing pattern of urban growth, our analysis reveals a significant decline of 19.45% in the area of agricultural land. Specifically, the agricultural land area decreased from 5,807.7 ha in 2002 to 4,678.29 ha in 2014, as indicated in Table 1 & Figure 3. There are various factors that contribute to the decrease in agricultural land:

1. The transformation of agricultural lands into residential areas to meet the needs of a growing population and expanding urban areas.
2. The abandonment of agricultural lands affected by saltwater intrusion following the 2004 tsunami is discussed in a study by Mukherjee *et al*. (2019) [30].

There is growing concern about the decrease in agricultural land area and its impact on food security and the preservation of traditional agricultural practices in the island ecosystem. It emphasizes the importance of implementing policies that support sustainable agriculture and safeguard valuable agricultural lands from being converted for alternative purposes.

Beach and Coastal Dynamics

1. The present study revealed that the beach area experienced a remarkable growth of 52.27% over the span of 12 years. Specifically, it expanded from 1,840.68 ha in 2002 to 2,802.87 ha in 2014, as depicted in Table 1 & Figure 3. The significant rise in levels can be linked to the impact of the 2004 tsunami, which caused geomorphological alterations and the accumulation of sediments along coastal regions [31].
2. The potential uplift of coastal areas resulting from tectonic activities related to the 2004 earthquake has been studied by Meltzner *et al*. (2006) [32].

Although the expansion of beach area may appear advantageous for tourism, it is important to carefully examine the ecological consequences of these alterations.

Vegetation Health Assessment

The analysis of the Vegetation Condition Index (VCI), Temperature Condition Index (TCI), and Vegetation Health Index (VHI) offers valuable insights into the overall ecological health of the South Andaman District. These indices, as shown in Figures 4, 5 and 6, provide a comprehensive understanding of the district's Vegetation Health Assessment.

Assessing the Health of Vegetation: The VCI maps (Figure 4) illustrate a distinct spatial pattern in vegetation condition throughout the South Andaman District. The elevated, forested areas of the island predominantly exhibit higher VCI values, which suggest favorable vegetation conditions. It can be inferred from this pattern that the island's topography has a significant impact on the growth of vegetation.

On the other hand, areas of human settlement, agricultural lands, and around Port Blair show lower VCI values. This pattern aligns with the effects of urbanization and intensified land use on the health of vegetation, as seen in similar tropical areas [33]. The strain on vegetation in these areas may be linked to various factors, including decreased soil moisture, heightened impervious surfaces, and the impact of the altered heat-scape of the Island [34].

The TCI maps (Figure 5) offer valuable insights into the thermal conditions that impact the health of vegetation. Urbanized areas and regions with reduced vegetation cover tend to have lower TCI values, which in turn indicate higher land surface temperatures. This pattern aligns with the urban heat island effect, which refers to the phenomenon of built-up areas having higher surface temperatures than the surrounding vegetated areas [35].

Forested areas and regions with dense vegetation cover tend to exhibit higher TCI values, which suggest cooler conditions. This pattern highlights the significant role that forest cover plays in regulating local climate conditions and mitigating the effects of climate change [36].

Vegetation Health Index (VHI): The VHI maps (Figure 6) offer a comprehensive perspective on the overall health of vegetation in the South Andaman District by combining information on moisture and thermal conditions. The spatial patterns observed in the VHI maps closely resemble the patterns seen in the VCI and TCI maps. Forested and elevated areas exhibit healthier vegetation conditions, while urbanized and agriculturally intensive regions show more stressed conditions.

The analysis conducted emphasizes the significance of striking a balance between development activities and the preservation of natural vegetation cover. The island's interior forested regions are home to areas with high VHI values, which play a vital role in preserving biodiversity and offering essential ecosystem services like carbon sequestration and water regulation [37].

Environmental Zoning

The environmental zoning approach for the South Andaman District, as presented in Table 2, offers a well-rounded strategy that aims to strike a balance between ecological preservation and sustainable development. This zoning plan acknowledges the various ecosystems found in the district and their environmental importance, while also taking into account human requirements and economic activities [9].

The fringe corals, designated as a marine environmental park, have a dual function. These areas not only promote tourism in extensive coral banks, but also serve as natural sea defenses against tsunami waves. This approach recognizes the economic value of coral reefs for tourism while highlighting their crucial function in safeguarding coastal areas. Nevertheless, it is crucial to implement effective management strategies to avoid the over-exploitation and potential harm to these delicate ecosystems caused by excessive tourist activities.

The presence of mangrove vegetation along shore fringes and estuaries is widely acknowledged for its significance in fishing and tourism, as well as its crucial role in providing natural protection against tsunamis and cyclones. This emphasizes the diverse capabilities of mangrove ecosystems and emphasizes the importance of preserving and responsibly utilizing them.

The intermontane valley flats are designated for various human activities and the extraction of resources, such as agriculture, settlements, and infrastructure development with plantation gardens. While this acknowledges the risk of soil erosion from overuse, it also recognizes the importance of allowing for necessary human activities and economic development. This emphasizes the need for meticulous land use planning and implementation of soil conservation measures in these areas.

The Piedmont slopes of coastal hills are designated for the purpose of carefully transitioning land uses, with a focus on establishing plantation gardens and preserving the existing forest land. Once more, the plan acknowledges the possibility of soil erosion if these areas are excessively utilized, highlighting the importance of implementing sustainable land management practices.

Hill tops are set aside as natural reserves, safeguarding forests and their resources. This zoning acknowledges the significance of preserving undisturbed forest ecosystems due to their valuable contributions to ecosystem goods and services. Preserving these areas is of utmost importance in order to uphold biodiversity, regulate the local climate, and guarantee water security for the island.

Tectonic activities have resulted in the formation of raised beach terraces, which are now used for settlements and roads. This zoning strategy utilizes naturally elevated areas for human habitation, which could help mitigate the risks associated with sea-level rise and coastal hazards.

This approach to environmental zoning showcases a comprehensive understanding of the landscape in the South Andaman District, effectively balancing the need for conservation with the pressures of development. There are several challenges that may arise when implementing this zoning plan [9]. One of these challenges is ensuring that regulations are effectively enforced in the various zones. Additionally, managing conflicts between conservation and development interests is another key challenge that needs to be addressed. Lastly, it is important to adapt the plan to accommodate future changes in climate and socio-economic conditions.

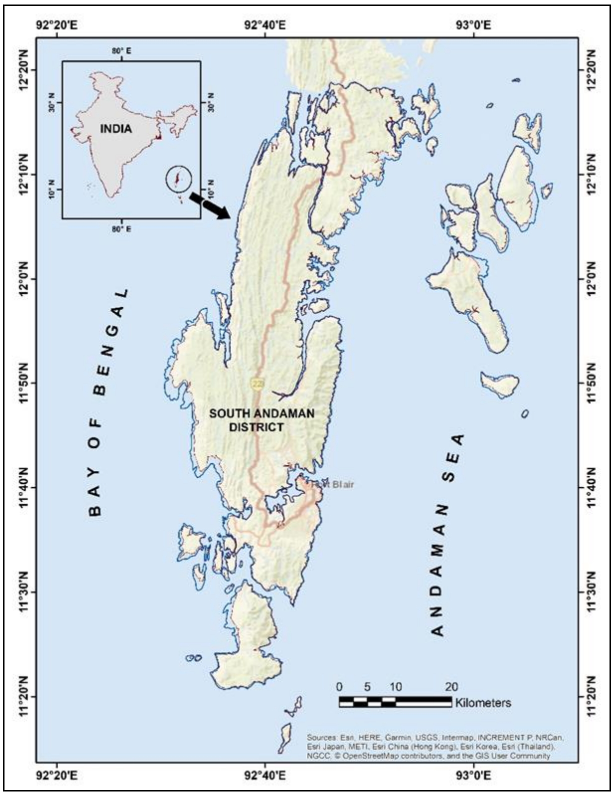

Fig 1: Location map of the study area

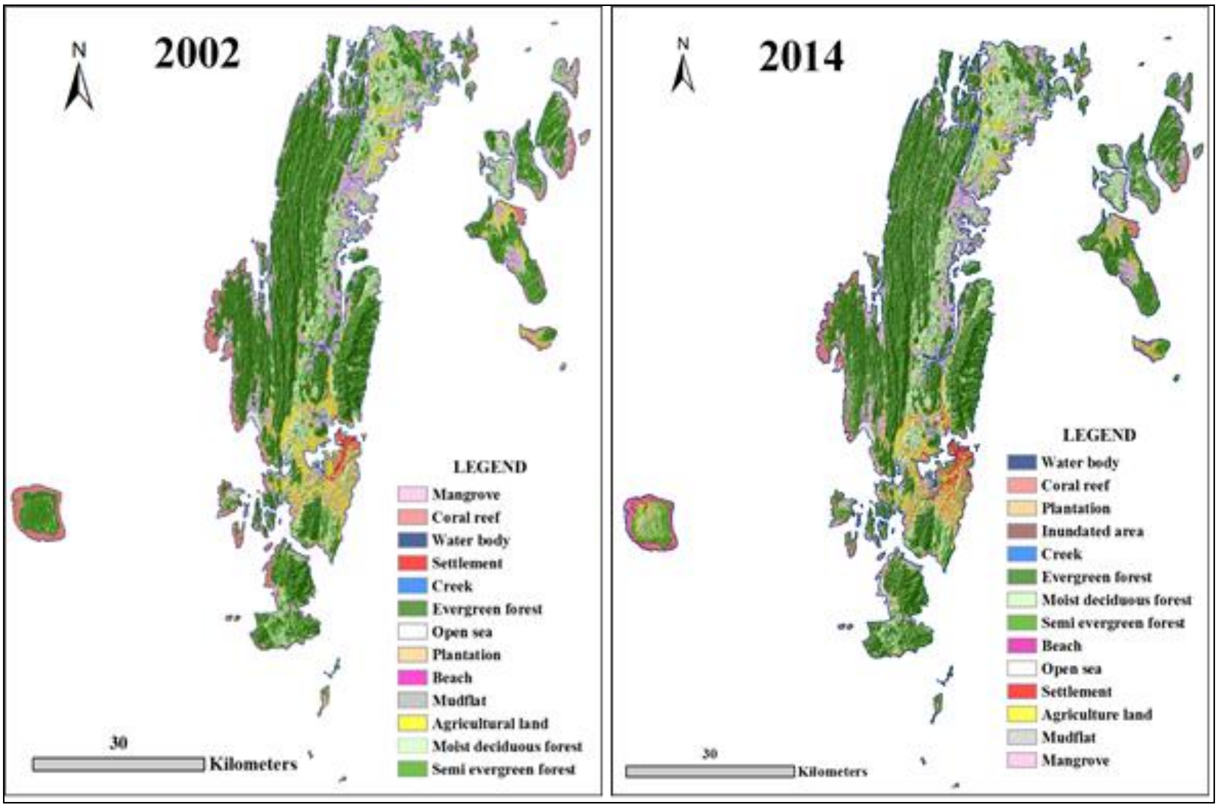

Fig 2: Land use/land cover maps of the South Andaman District for the years 2002 and 2014

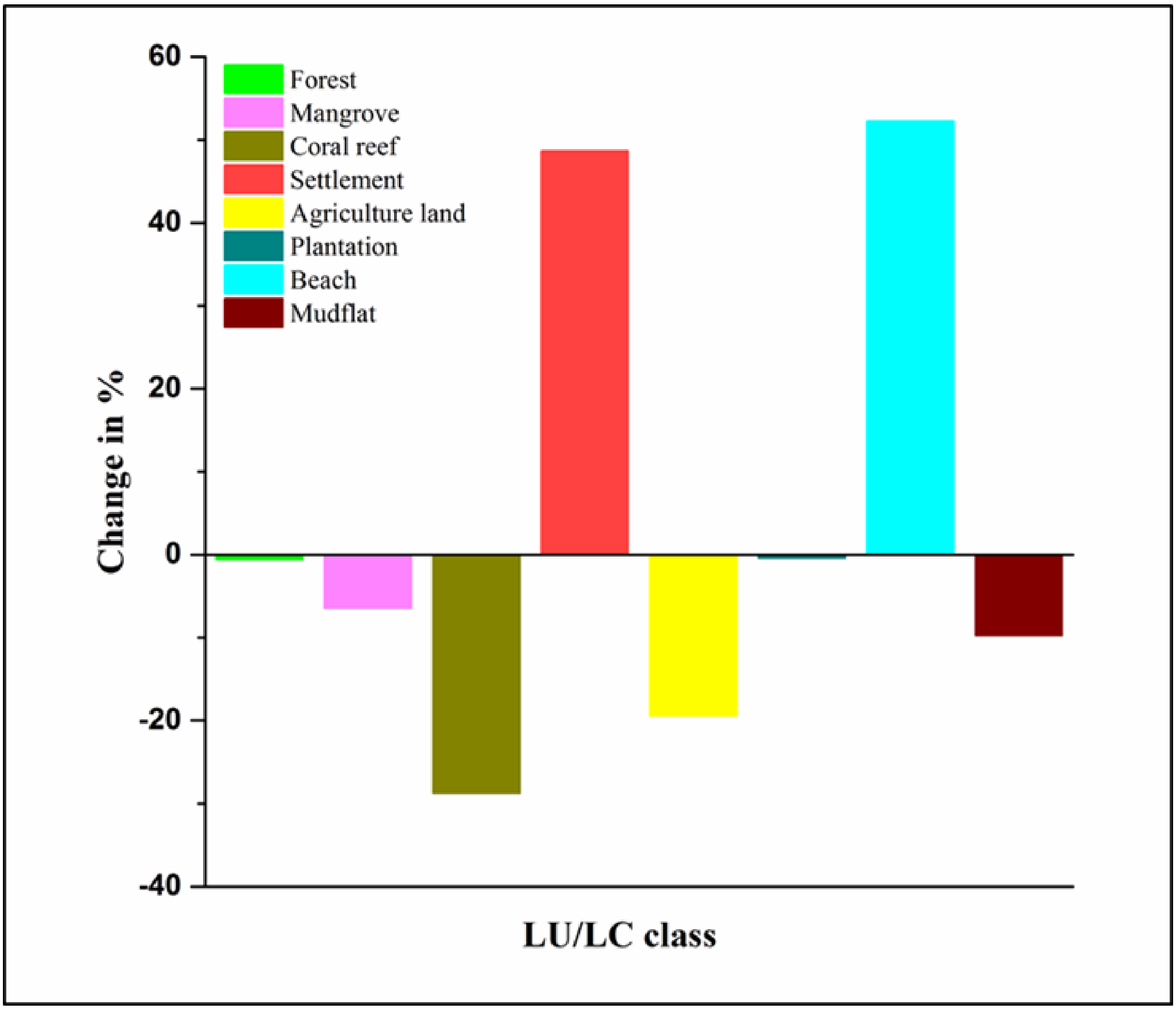

Fig 3: Percentage of land use/land cover changes from 2002 to 2014

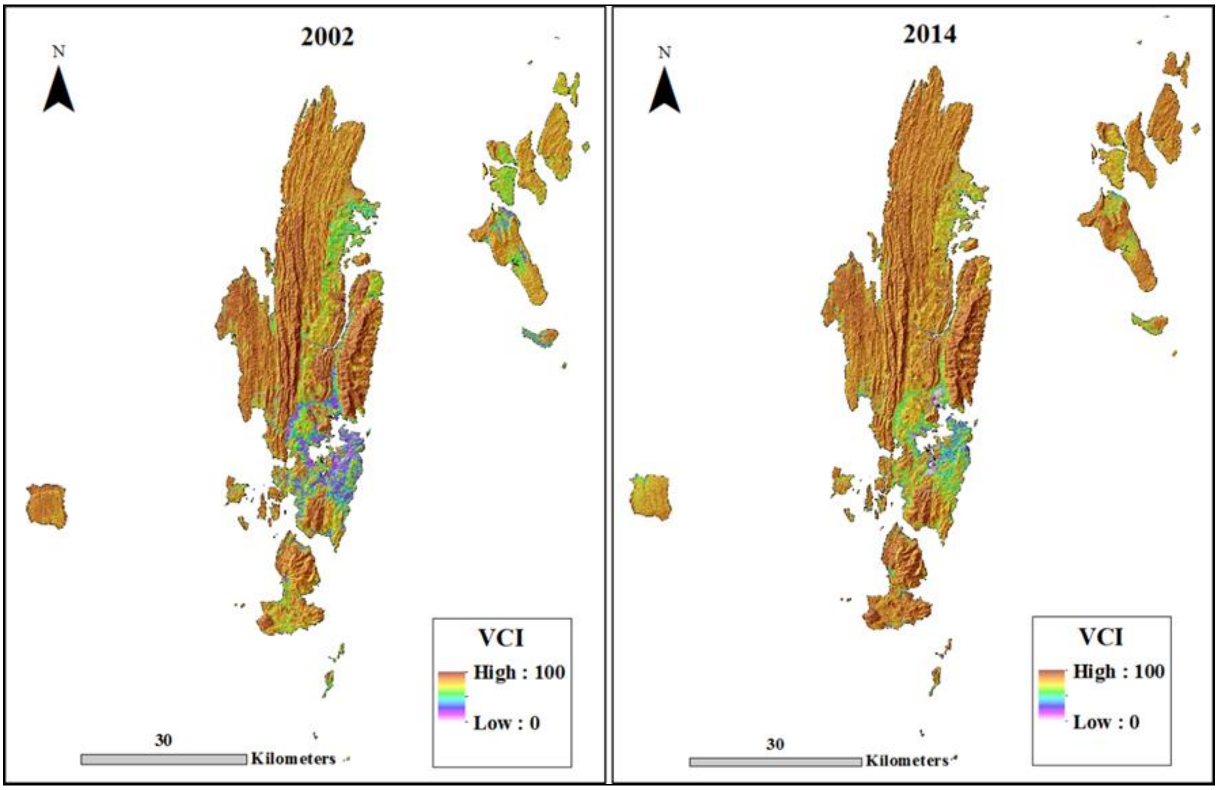

Fig 4: Vegetation Condition Index (VCI) Maps of South Andaman District for the years 2002 and 2014

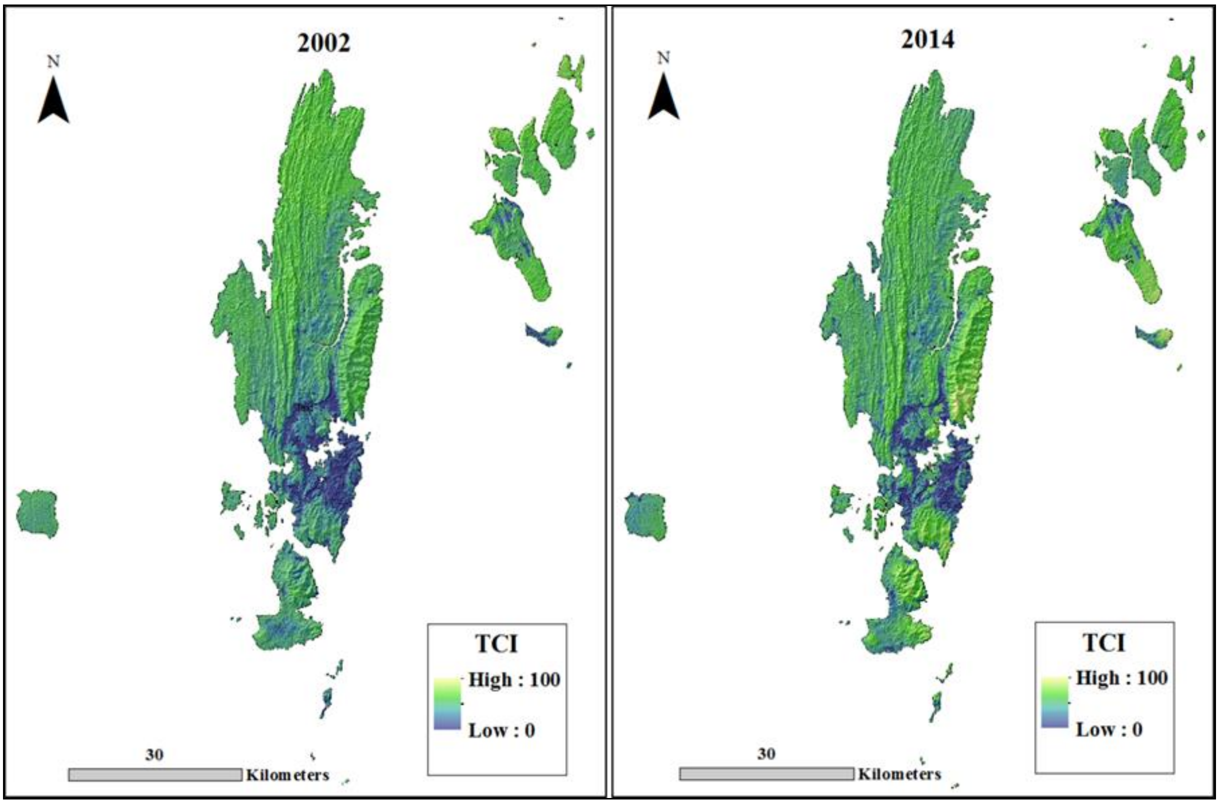

Fig 5: Temperature Condition Index (TCI) Maps of South Andaman District for the years 2002 and 2014

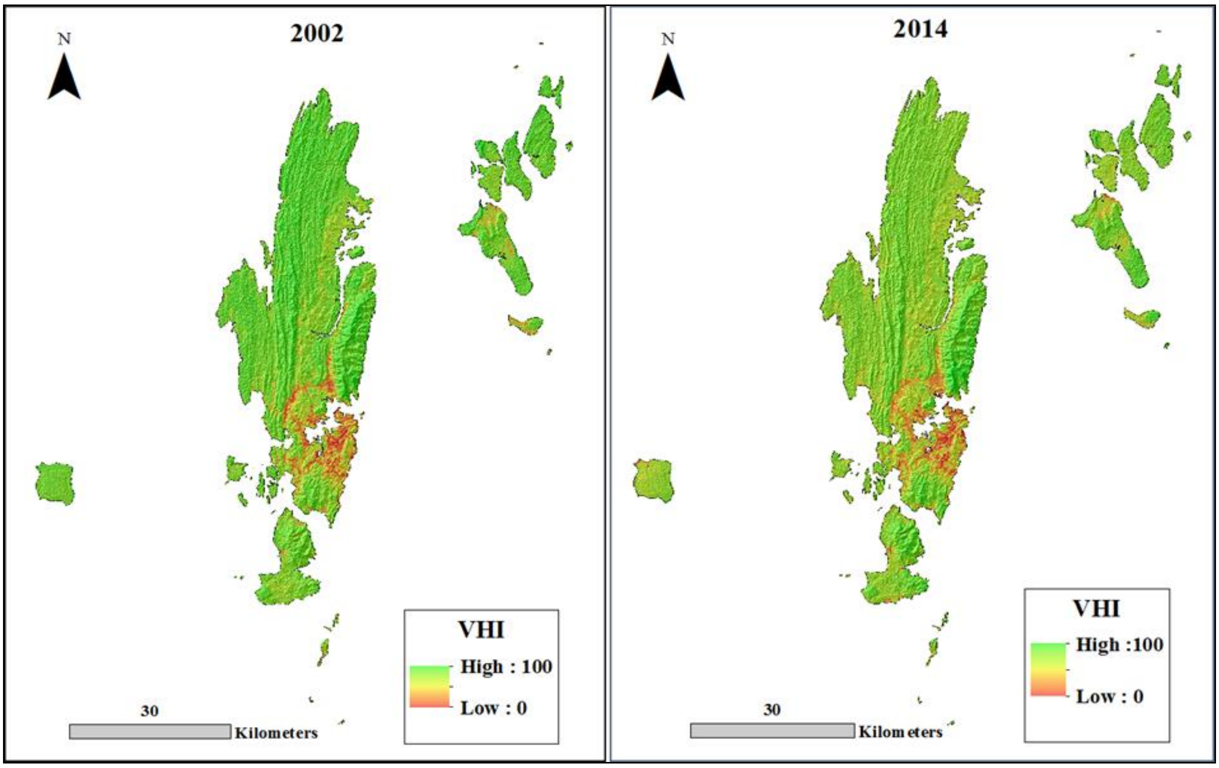

Fig 6: Vegetation Health Index (VHI) Maps of South Andaman District for the years 2002 and 2014

Table 1: Changes in areal extent of land use and land cover classes in the South Andaman District between 2002 and 2014

Types of environmental zone	Land use/land cover types	Environmental significance
Fringe corals as marine environmental park	Tourism in extensive coral bank	Natural sea defense as barrier against tsunami wave.
Mangrove vegetation with carbonate platforms along the shore fringes and estuaries	Fishing and tourism	Natural sea defense as barrier against tsunami and cyclone
Intermontane valley flats for human uses or resources extraction	Agriculture, settlement and infrastructure development with plantation garden	Overuse can produce soil erosion

Piedmont slope of the coastal hills for controlled conversion of land uses	Location of plantation garden and existing forest land	Overuse can promote the soil erosion
Hill tops of natural reserve	Forest and forest resources	Ecosystem goods and services
Raised beach terrace	Settlements and roads	Raised from the sea level by tectonic activities

Table 2: Proposed environmental zones for the South Andaman District

Class	Area in ha (2002)	Area in ha (2014)	Change area in ha	Change in %
Forest	132077.43	131281.02	-796.41	-0.60
Mangrove	13832.01	12941.19	-890.82	-6.44
Coral reef	13337.82	9504.72	-3833.1	-28.74
Settlement	1861.29	2767.59	906.3	48.69
Agriculture land	5807.7	4678.29	-1129.41	-19.45
Plantation	12653.46	12599.91	-53.55	-0.42
Beach	1840.68	2802.87	962.19	52.27
Mudflat	2818.08	2543.31	-274.77	-9.75

Conclusion

This study offers a thorough evaluation of changes in land use and land cover (LULC) as well as the health of vegetation in the South Andaman District. It uncovers noteworthy alterations in the island's landscape during the period from 2002 to 2014. Combining LULC change analysis with vegetation health indices provides a robust method for monitoring environmental changes and guiding sustainable management strategies in island ecosystems. Given the ongoing challenges of population growth, urbanization, and climate change in the South Andaman District, the results of this study provide a crucial starting point for future monitoring initiatives and can guide policymakers in making informed decisions for sustainable development and conservation. Further investigation should prioritize analyzing data at a more detailed time scale to capture rapid changes, incorporating socio-economic data to gain deeper insights into the factors influencing change, and creating predictive models to anticipate future alterations in the landscape. In addition, this study emphasizes the significance of geospatial technologies in offering a thorough understanding of environmental changes in island ecosystems. The findings highlight the pressing importance of adopting well-rounded and sustainable strategies for development that safeguard the distinct ecological legacy of the South Andaman District, all while addressing the demands of its expanding population.

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