

Natural and Manmade Induced Land Use and Land Cover Changes in Tribal Island Car Nicobar. Andaman and Nicobar Islands-A Geospatial Approach

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Abstract

Land Use and Land Cover (LULC) dynamics provide critical insights into the interaction between natural processes and anthropogenic activities in fragile island environments. The present study examines natural and human-induced LULC changes in Car Nicobar Island using geospatial techniques and multi-temporal satellite data. IRS-1D LISS-III (1998), Landsat TM (2006), and Landsat OLI/TIRS (2025) imagery were analysed to identify and quantify changes in major LULC categories. The analysis indicates substantial transformations following the 2004 Indian Ocean tsunami, reflected in changes in water bodies, sandy beaches, coral reefs, forest cover, settlements, and coastal features. Anthropogenic influences, including settlement expansion, infrastructure development, and land-use intensification, have further modified the island landscape. GIS-based change detection facilitated the spatial assessment and quantification of these transformations over time. The findings highlight the combined influence of extreme natural hazards and human activities on the island's ecological and landscape characteristics. The study provides valuable baseline information for sustainable land-use planning, environmental management, and disaster-resilient development of Car Nicobar Island.

Key Words: Tribal Island, Remote Sensing, LULC, Disaster Resilient, Anthropogenic

1. Introduction

Land use and land cover (LULC) are fundamental indicators of environmental conditions and human interactions with the Earth's surface. Land cover refers to the physical features present on the land, such as forests, agricultural land, water bodies, settlements, and barren land, whereas land use describes how these resources are utilized for agriculture, habitation, transportation, and other socio-economic activities (Lambin, Geist, & Lepers, 2003). Monitoring LULC changes is essential because these changes influence biodiversity, ecosystem services, hydrological processes, and climate, while also providing critical information for sustainable land management and disaster risk reduction (Turner et al., 2007).

Small island ecosystems are highly sensitive to both natural and anthropogenic disturbances due to their limited land resources, fragile ecosystems, and exposure to multiple hazards. The Andaman and

Nicobar Islands, situated along the active Andaman–Sumatra subduction zone, are frequently affected by earthquakes, tsunamis, cyclones, coastal erosion, and sea-level changes (Gahalaut et al., 2006). In addition to these natural processes, expanding settlements, infrastructure development, transportation networks, and changes in agricultural practices have significantly altered land use patterns across the islands (Reddy et al., 2016).

Car Nicobar Island is one of the most environmentally sensitive islands in the Nicobar group. The island experienced severe environmental and socio-economic impacts during the 26 December 2004 Indian Ocean tsunami, which resulted in coastal inundation, land subsidence, destruction of settlements, loss of coconut plantations, shoreline modification, and salinization of agricultural land (Mishra et al., 2007; Gahalaut et al., 2006). Subsequent rehabilitation programmes and developmental activities have further influenced the spatial distribution of land use and land cover, making it essential to evaluate long-term landscape changes. Advances in Remote Sensing and Geographic Information Systems (GIS) have made it possible to monitor LULC changes accurately over time. Multi-temporal satellite imagery enables the detection and quantification of changes in vegetation, settlements, agricultural land, and coastal environments, while GIS provides an effective platform for analysing spatial patterns and identifying areas undergoing significant transformation (Jensen, 2015; Lillesand, Kiefer, & Chipman, 2015). These geospatial techniques have become indispensable for assessing environmental changes, especially in remote island regions.

Therefore, the present study adopts a geospatial approach to examine natural and man-made induced land use and land cover changes in Car Nicobar Island. The study aims to analyse the spatial and temporal patterns of LULC transformation and identify the major driving factors influencing landscape change.

2. Study Area

Car Nicobar is the northernmost inhabited island of the Nicobar group in the Andaman and Nicobar Islands, India. It lies between 9°10'–9°30' N latitude and 92°45'–93°00' E longitude in the eastern Indian Ocean and covers an area of approximately 127 km² (Survey of India, 2011). Administratively, the island forms the headquarters of the Nicobar district and is inhabited predominantly by the indigenous Nicobarese community, whose settlements are concentrated along the coastal plain (Census of India, 2011). Unlike the rugged islands of the Andaman group, Car Nicobar is characterized by a low-lying, gently undulating coral platform, with elevations generally below 15 m above mean sea level (Singh et al., 2011). The island experiences a tropical maritime climate, receiving an average annual rainfall of about 2,800–3,000 mm, mainly during the southwest and northeast monsoons, while temperatures remain relatively uniform throughout the year (India Meteorological Department, 2020). Dense coconut plantations, littoral forests, settlements, and coastal vegetation constitute the major land use and land cover (LULC) classes on the island (Forest Survey of India, 2023).

Car Nicobar gained global attention after the 26 December 2004 Indian Ocean tsunami, which caused extensive coastal inundation, shoreline modification, land subsidence, and widespread destruction of settlements and coconut plantations (Malamud et al., 2005; Chandrasekharam, 2005). Following the disaster, large-scale rehabilitation, infrastructure development, and reconstruction activities significantly

altered the spatial distribution of land use, particularly in coastal areas (NDMA, 2010). In addition to these anthropogenic changes, natural processes such as coastal erosion, vegetation regeneration, and geomorphic adjustments have continued to influence the landscape over time (Dharanirajan et al., 2007).

The unique combination of tsunami-induced disturbances and post-disaster human interventions makes Car Nicobar an ideal case for analysing long-term LULC dynamics using geospatial techniques. Multi-temporal satellite imagery and Geographic Information System (GIS) tools provide an effective framework for quantifying these changes, identifying vulnerable coastal zones, and understanding the relative influence of natural and human-induced processes on landscape transformation (Lillesand et al., 2015; Jensen, 2016).

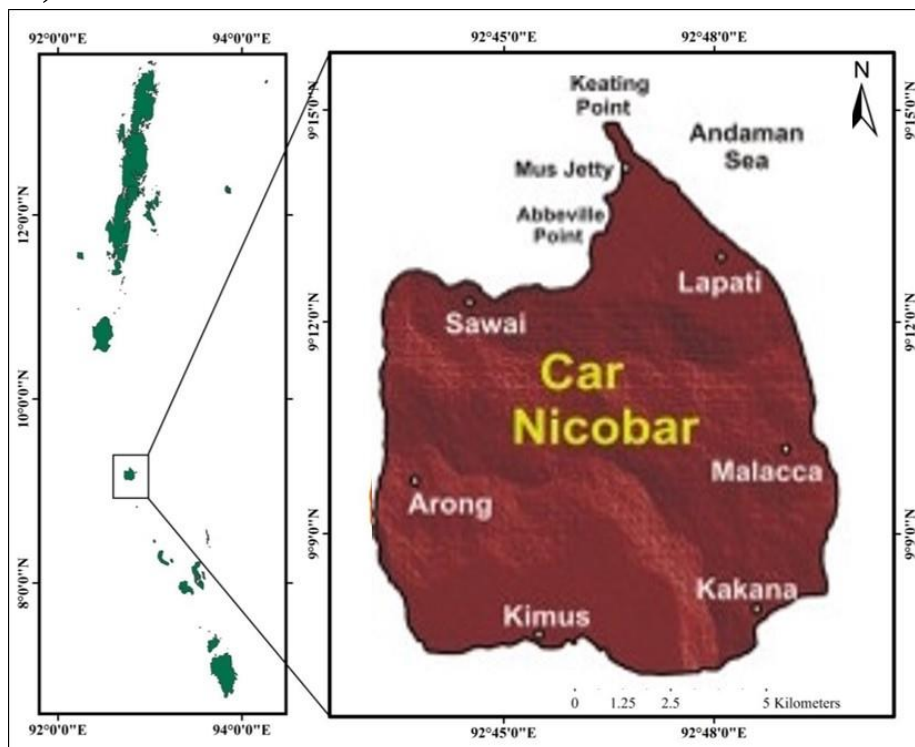


Fig: 1 Study Area

Material

Multi-temporal satellite data (1998) IRS-LISS-III IRS-P6-LISS-IV 2006 (Indian Remote sensing Satellite-Linear Imaging Self Sensing Scanner) were obtained from the National Remote Sensing Agency (NRSA) and Landsat OLI/TIRS C2 L2 (2024) satellite data were downloaded from USGS web site National Aeronautics Space Administration (NASA), USA. Secondary population data were collected from (Census of India, 2011) and other relevant information collected from government reports, books, journals and websites to achieve the objectives of the present investigation.

Methods

The assessment of natural and man-made induced Land Use and Land Cover (LULC) changes in Car Nicobar Island was carried out using multi-temporal satellite imagery integrated with Remote Sensing and Geographic Information System (GIS) techniques. Three satellite datasets representing different time

periods were employed: IRS-1D LISS-III (1998), Landsat TM (2006), and Landsat 8 OLI/TIRS Collection 2 Level-2 (2025). These datasets enabled the analysis of long-term spatial and temporal changes in land use and land cover before and after the 2004 Indian Ocean tsunami.

A Survey of India (SOI) topographic map at a scale of 1:50,000 was used as the base reference for image geo-referencing and co-registration to ensure spatial consistency among the satellite datasets. The base map of the study area was prepared from the SOI toposheet, and all satellite images were geometrically corrected to the UTM Zone 46N projection with the WGS 84 datum. Land use and land cover maps were prepared through visual image interpretation followed by on-screen digitization in a GIS environment. The classification was carried out according to the Level-II Land Use/Land Cover Classification System developed by the Space Applications Centre (SAC), ISRO (1991). Image interpretation was based on standard visual interpretation elements, including tone or colour, texture, pattern, shape, size, shadow, location, and association, to accurately identify different land use and land cover categories.

The digitized LULC maps were edited, labelled, and integrated into the GIS database. Spatial analysis and area estimation of each land use category were performed using ArcMap 10.2. The Intersect and Overlay tools were applied to compare the classified maps of 1998, 2006, and 2025 and to generate LULC change maps. Area statistics for each land use and land cover class were computed to quantify spatial changes over the study period, and the results are presented in Tables: 1 and 2.

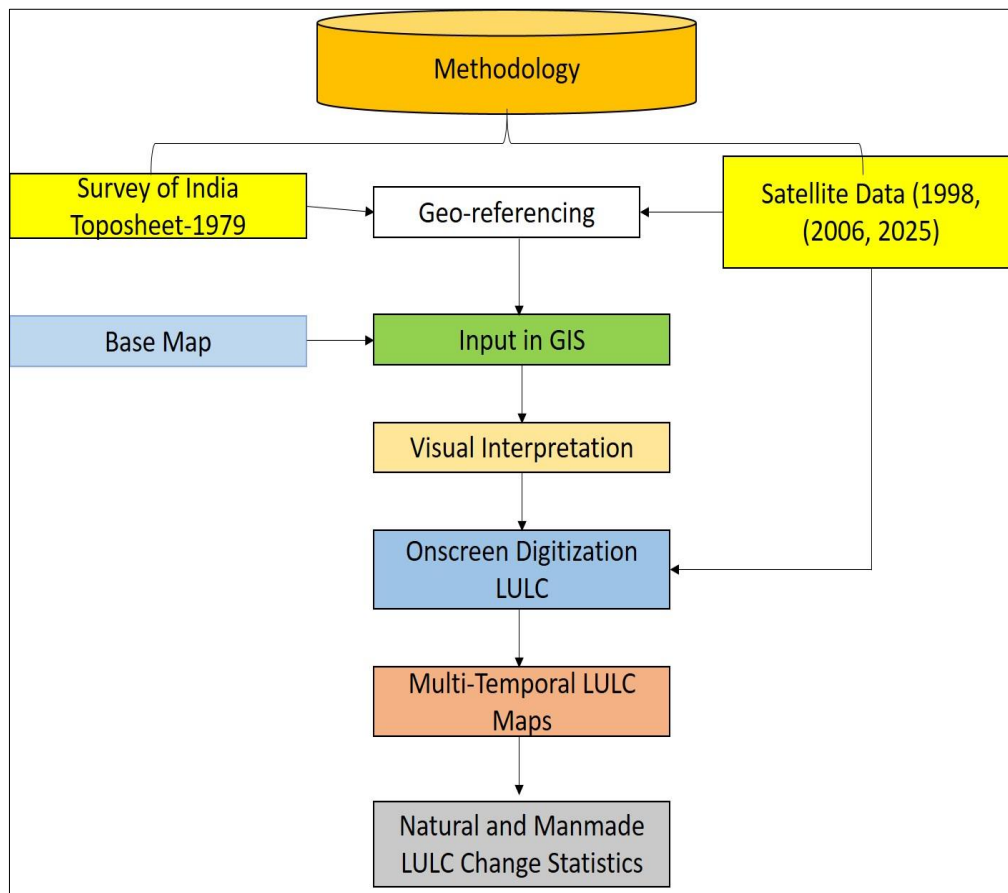


Figure: 2 Methodology

3. Result and Discussion

The LULC maps of study area have been categorized into eleven different classes viz. Forest, Settlement with Vegetation, and Degraded Settlement with Vegetation, Coral Reef, Degraded Coral reef, Sandy Beach, Creek, Waterbody, Swampy Land, Water Inundation, Jetty and Air Port. Pre tsunami Land use land cover of the study area reveals varying LULC changes.

Table: 1 Pre and Post tsunami Land use Land Cover (1998- 2006)

Pre Tsunami LULC 1998	Area in Ha	Post Tsunami LULC 2006	Area in Ha	Change	%
Forest	10945	Forest	9683	-1262	73.82
Degraded Forest	133	Degraded Forest	609	476	4.64
Settlement with Vegetation	996	Settlement with Vegetation	1251	254	9.53
	0	Degraded Settlement with Vegetation	245	245	1.86
Coral Reef	460	Coral Reef	365	-95	2.78
Waterbody	109	Degraded Coral	124	124	0.94
Sandy Beach	294	Sandy Beach	278	-16	2.12
Creek	15	Creek	120	104	0.91
Swampy Land	113	Water Inundation	384	270	2.92
Jetty	1.2	Jetty	8	7	0.06
Air Port	46	Air Port	47	1	0.35
Total	13116	Total	13116		100

Table: 2 Pre and Post tsunami Land use Land Cover (2006- 2025)

Post Tsunami LULC 2006	Area in Ha	Current Status of LULC 2025	Area in Ha	Change in Ha	%
Forest	9683	Forest	11265	1582	85.5
Degraded Forest	609	Degraded Forest	113	-496	0.8
Settlement with Vegetation	1251	Settlement with Vegetation	622	-629	4.7
Degraded Settlement with Vegetation	245		0	245	0
Coral Reef	365	Coral Reef	384	19	2.9
Degraded Coral	135	Degraded Coral	157	22	1.1
Sandy Beach	278	Sandy Beach	172	-106	1.3
Creek	120	Creek	83	-37	0.6
Water Inundation	384	Water Inundation	65	-319	0.4
Jetty	8	Jetty	6	-2	0.04
Air Port	36	Air Port	47	11	0.3
		Swampy Land	249	249	1.8

Total	13116	Total	13116	100
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Natural and Manmade the comparative analysis of land use and land cover (LULC) between 1998 (pre-tsunami) and 2006 (post-tsunami) and current status (2025) reveals significant transformations in the study area. The total geographical area remained constant at 13,116 hectares; however, major shifts occurred within individual land cover categories due to the impact of the tsunami. Natural ecosystems such as forests and coral reefs experienced considerable degradation, while certain categories like degraded forest, water inundation, and settlement areas showed notable increases. These changes reflect the combined effects of natural disaster impact and subsequent environmental and human responses.

Forest Cover

The forest is one of the most intricate ecosystems, providing sustenance and habitat for a diverse range of flora and fauna. The predominant feature class in the study area is forest cover. The forest cover was discerned by its crimson hue, sleek texture, and irregular form on the satellite imagery. Forest area, which dominated the landscape in 1998 with 10,945 hectares, declined significantly to 9,683 hectares in 2006. This represents a loss of -1,262 hectares, accounting for approximately 73.8% of the total change (Table: 1; Figure: 3). The reduction in forest cover is primarily attributed to the destructive force of the tsunami, which uprooted vegetation, caused soil erosion, and altered the coastal and inland ecological balance.

The decline in forest cover also suggests secondary impacts such as salinization of soil, which inhibits plant regeneration. Additionally, fallen trees and damaged vegetation may have led to fragmentation, reducing ecological stability. This loss has serious implications for biodiversity, carbon sequestration, and ecosystem services (Kumar et al. 2007).

In 2006, the forest area in Car Nicobar was recorded as 9683 ha, which significantly increased to 11265 ha by 2025. This gain of 1582 ha reflects strong post-tsunami ecological recovery. The increase indicates successful natural regeneration and possibly conservation efforts over the years. The forest now dominates the land use pattern, accounting for the highest percentage share (85.8%) in 2024 (Table: 2, Figure: 4 and 5).

Degraded Forest

The degraded forest category increased dramatically from 133 hectares in 1998 to 609 hectares in 2006, showing an increase of 476 hectares (4.6%) (Table: 1, Figure: 3). This indicates that a substantial portion of intact forest was transformed into degraded conditions rather than being completely lost. The increase in degraded forest suggests partial damage rather than total destruction. Factors such as saltwater intrusion, sediment deposition, and physical damage to vegetation contributed to this transition. It also indicates the beginning of ecological recovery, where damaged forests have not fully regenerated but still retain some vegetative structure. In the study area degraded forest observe in the coastal regions of the study area such as Mus, Big Lapathy, Small Lapathy, Tapoiming, Chukchuka, Kinyka, Tamaloo, Perka, Malacca, IAF Camp, Kakana, Kimus, Arong, Tee Top and Sawai (Kumar et al. 2007).

The degraded forest area showed a remarkable decline from 609 ha in 2006 to only 113 ha in 2025, representing a reduction of 496 ha. This trend suggests that previously degraded forest patches have been restored into healthier forest cover. It highlights an improvement in vegetation quality and ecosystem stability over time (Table: 2, Figure: 4 and 5).

Settlement with Vegetation

Settlement with vegetation refers to a human habitation established in a specific location or region as a result of agricultural and non-agricultural activities. The satellite imagery revealed a settlement characterized by a light yellow hue, red undertones, irregular patches, and an association with vegetation. Settlement with vegetation constitutes the second largest land use and land cover feature class in the study area.

Settlement with vegetation increased from 996 hectares to 1,251 hectares, showing a gain of 254 hectares (9.5%) in the year of 1998 to 2006 (Table:1, Figure: 3). This reflects expansion or modification of human habitation areas, possibly due to post-tsunami rehabilitation and reconstruction activities.

Settlement with vegetation decreased from 1251 ha in 2006 to 622 ha in 2025, showing a loss of - 629 ha (Table: 2, Figure: 4 and 5). This reduction may indicate changes in settlement patterns, such as conversion into more built-up areas or transformation into other land use categories like forest. It may also reflect post-tsunami relocation or restructuring of settlements.

Degraded Settlement with Vegetation

This land-use category was absent in 1998 but emerged over 245 ha in 2006 following the 2004 tsunami (Table: 1, Figure: 3). It represents partially damaged settlements with surviving vegetation, reflecting tsunami-induced destruction and subsequent recovery. The largest affected areas were observed in Mus, Big Lapathy, Small Lapathy, Tapoiming, Chukchucha, Kinyuka, Tamaloo, Perka, Malacca, IAF Camp, Kakana, Kimious, Arong, Tee Top, and Sawai, with particularly extensive degradation in Mus, Big Lapathy, Small Lapathy, Tapoiming, Chukchucha, Kinyuka, Tamaloo, Perka, Malacca, IAF Camp, and Kakana. This pattern highlights the spatial extent of tsunami damage and post-disaster landscape transformation.

Coral Reef

Coral reefs are highly diverse and sensitive marine ecosystems that support biodiversity, protect coastlines, and sustain fisheries and tourism (Veron, 1995; Birkeland, 1997; Wilkinson and Bernand, 1999). In satellite imagery, coral reefs were identified by their turquoise-blue tone, irregular shape, smooth texture, and association with submerged rocks. Coral reef area declined from 460 ha in 1998 to 365 ha in 2006, a loss of 95 ha, while 124 ha of degraded coral emerged following the 2004 tsunami (Table: 1, Figure: 3). This reflects damage caused by wave action, sedimentation, and changes in marine conditions. By 2025, coral reef area increased slightly to 384 ha, (Table: 2, Figure: 4 and 5) indicating partial recovery; however, regeneration remains slow due to continuing environmental pressures and the need for effective conservation measures.

Degraded Coral

Degraded Coral reef was identified by its white tone, smooth and linear texture, located at on reef flat and associate with reef flat surrounding. Pre tsunami (1998) in the study area there is no degraded corals were found but in the year (2006) degraded corals were identified in the study area coral area increased from 124 ha in 2006 to 157 ha (Table: 1, Figure: 3). in 2025, showing a rise of 33 ha (Table:1, Figure: 4 and 5). This indicates that while some coral reefs are recovering, a portion is still undergoing degradation, possibly due to climate change, ocean stress, or human interference.

Sandy Beach

Sandy beaches, identified by their bright white to yellow tone on satellite imagery, decreased from 294 ha in 1998 to 278 ha in 2006, indicating minor tsunami-induced geomorphological changes (Table:1, Figure: 3). By 2025, the sandy beach area further declined to 172 ha, a loss of 106 ha (Table: 2, Figure: 4 and 5). This reduction reflects continued coastal erosion, shoreline modification, and sediment redistribution associated with the 2004 tsunami, sea-level rise, and wave action, with implications for coastal stability and ecosystems.

Creek

Creek area increased from 15 hectares to 120 hectares, showing a slight expansion. This suggests that the tsunami may have widened existing creeks or created new channels through erosion. The creek area reduced from 120 ha in 2006 to 83 ha in 2025, showing a decrease of -37 ha (Table: 2, Figure: 4 and 5). this suggests changes in drainage patterns and sediment deposition, possibly linked to post-tsunami geomorphological adjustments.

Waterbody

Water bodies, identified by their dark blue tone on satellite imagery, are important for domestic use and minor irrigation. The water body area increased from 109 ha in 1998 to 384 ha in 2006 (Table: 1 and 2) due to the 2004 tsunami. This increase reflects tsunami-induced inundation, land subsidence, shoreline modification, and saltwater intrusion, resulting in significant hydrological changes with potential impacts on freshwater resources, agriculture, and coastal ecosystems.

Water Inundation

26th December 2004 Earthquake (*M* w 9.3) leads to subsidence of Car Nicobar Island and sea water inundation (Malik and Murthy, 2005) in forest, settlement with vegetation, sandy beach and forest. Sea water inundation is identified by its dark gray tone in the satellite imageries.

In the year 1998 no water inundation has been observed in the study area. Post tsunami water inundation observed from 384 ha in 2006 to only 65 ha in 2025, with a reduction of -319 ha (Table: 2, Figure: 4 and 5). This indicates that areas previously affected by tsunami-induced flooding have largely recovered and drained over time.

Swampy Land

Swampy land covered 113 hectares in 1998 (Table: 1) but its condition changed significantly after the tsunami. In the year 2006 after tsunami the swampy land appears to have been transformed into water

inundation areas or expanded wetland zones due to prolonged seawater intrusion (Figure: 3). But 2025 the swampy land calculated 249 ha it due to back recede of the tsunami water (Table: 2, Figure: 4 and 5). The tsunami led to increased salinity, waterlogging, and poor drainage conditions, which altered the natural characteristics of these areas. As a result, swampy lands either expanded into low-lying regions or merged with newly formed water bodies and inundated zones. This transformation indicates a shift towards more unstable and saturated land conditions, reducing the suitability of these areas for vegetation growth and human use.

Jetty

The jetty area increased substantially from 1.2 ha in 1998 to 8 ha in 2006, reflecting post-tsunami reconstruction and efforts to restore coastal connectivity and economic activities (Table: 1 and 2). By 2025, the jetty area declined to 6 ha. Possibly due to coastal erosion, shoreline changes, infrastructure modification, or improved land-use classification. Overall, the observed changes indicate the dynamic nature of coastal infrastructure following the 2004 tsunami.

Airport

The airport area remained almost unchanged, increasing marginally from 46 ha in 1998 to 47 ha in 2006, indicating that tsunami impacts on airport infrastructure were minimal or that facilities were restored rapidly. The area remained at 47 ha in 2025 (Table 1 and 2), reflecting limited expansion associated with infrastructure improvement and post-tsunami development. This stability suggests the airport has continued to play an important role in connectivity and administrative functions while causing only minor land use changes.

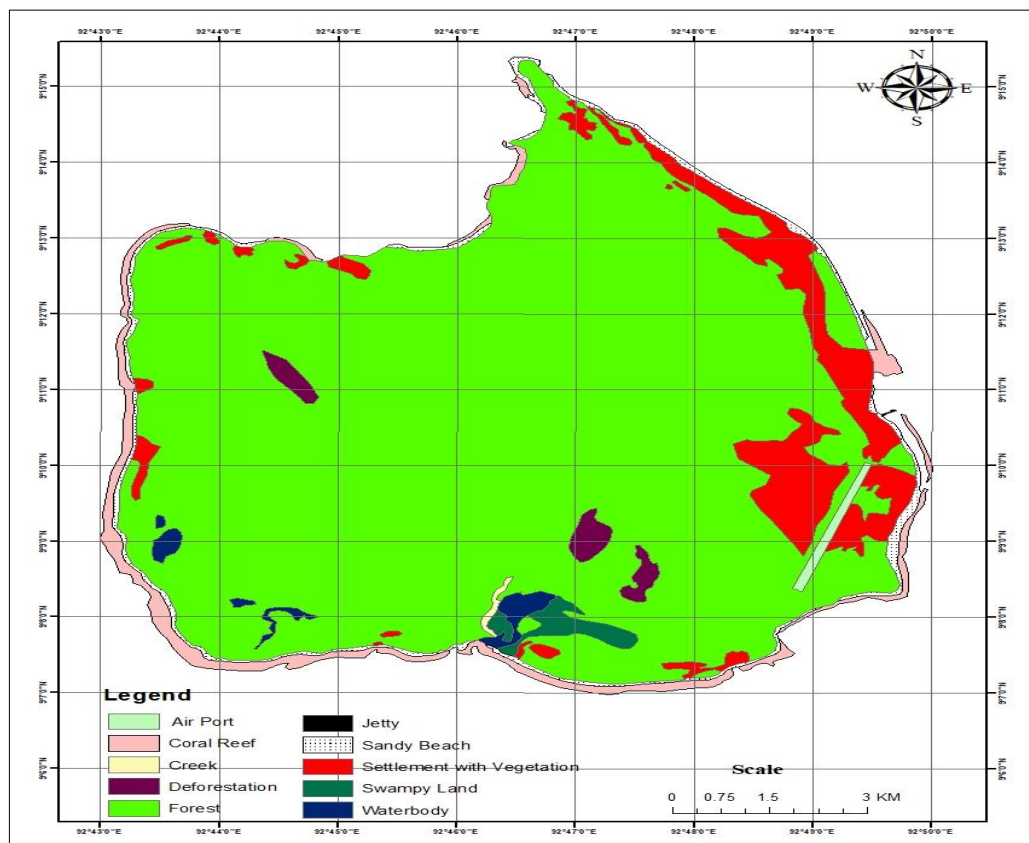


Fig: 3 Land Use Land Cover (1998)

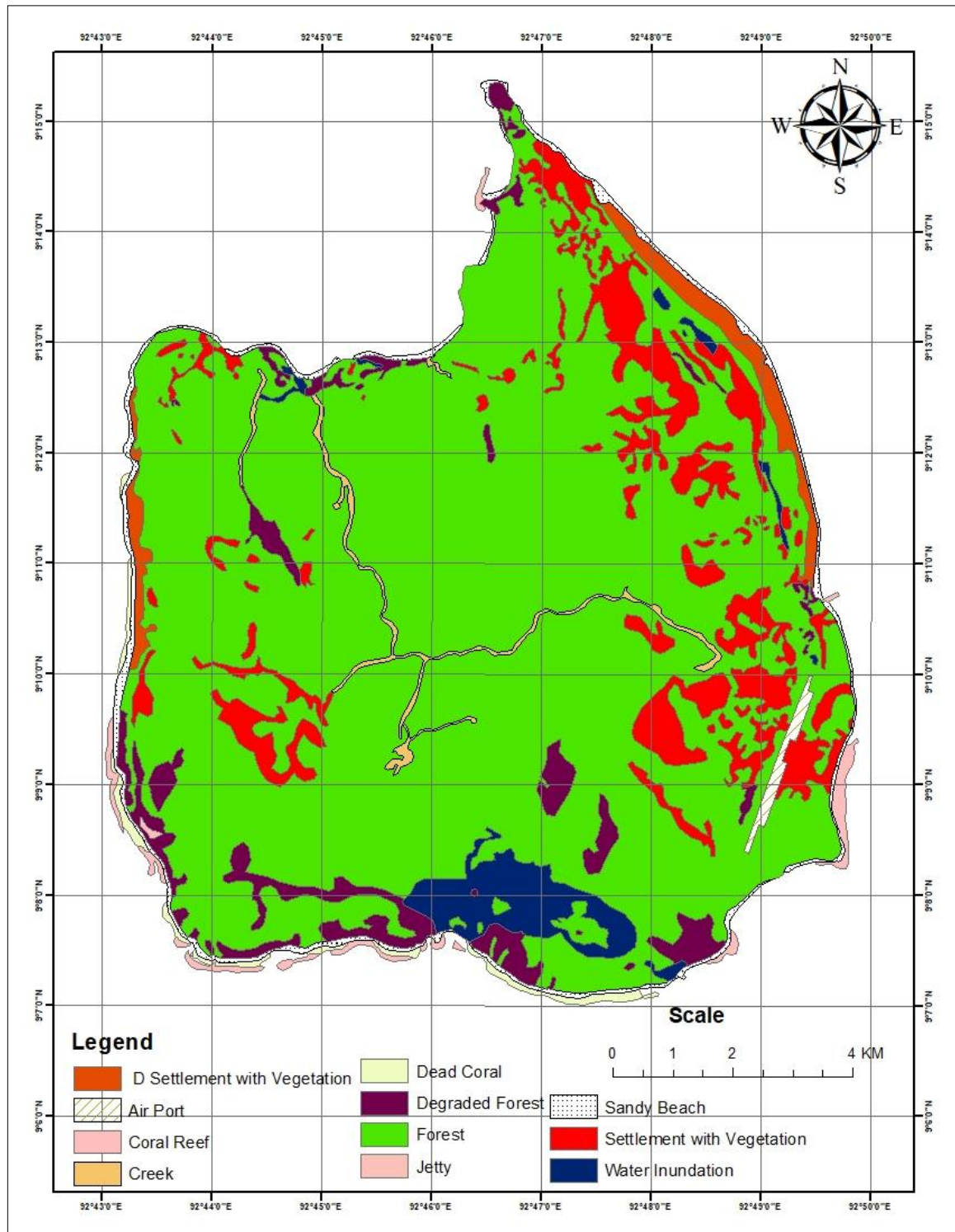


Fig: 4 Land Use Land Cover (2006)

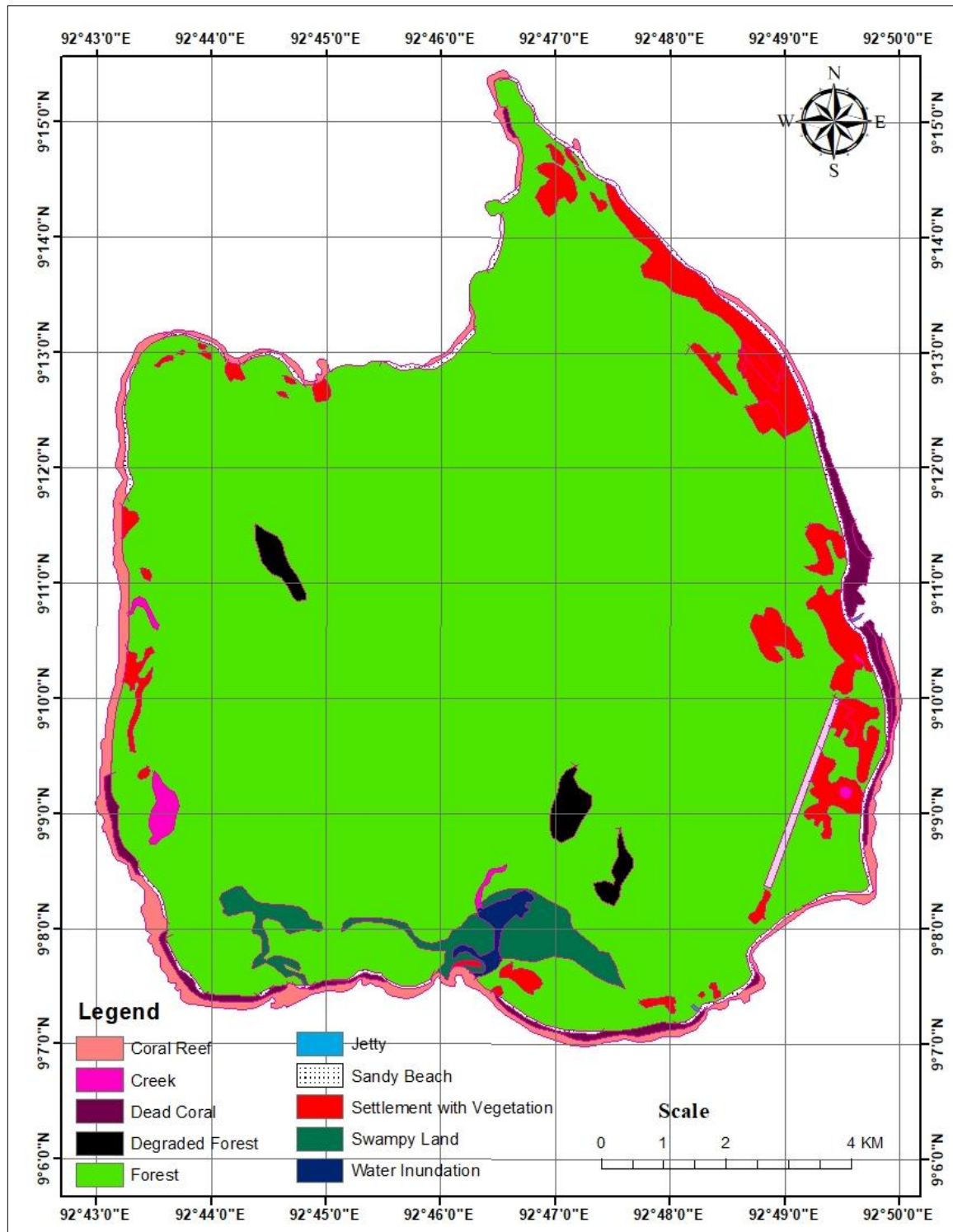


Fig: 5 Current Status of Land Use Land Cover (2025)

4. Conclusion

The comparative assessment of LULC changes from 1998 to 2006 and 2006 to 2025 highlights the dynamic nature of coastal landscapes in Car Nicobar Island. The transition from pre-tsunami stability to post-tsunami disturbance demonstrates the severe impact of natural disasters on land cover patterns. The

2006 scenario represents a phase of maximum disruption, characterized by loss of vegetation, damaged settlements, and increased inundation zones.

The post-2006 to 2025 period reflects a phase of recovery and adaptation. Natural regeneration processes have restored portions of vegetation cover, while human-driven reconstruction has reshaped settlement patterns and land use practices. However, the recovery is not entirely ecological; it is accompanied by increasing anthropogenic pressure, leading to changes in land use intensity and environmental stress. The decline in certain natural features such as coastal vegetation and mangroves raises concerns about future vulnerability to hazards.

Overall, the study demonstrates that Remote Sensing and GIS are highly effective tools for monitoring long-term LULC changes and disaster impacts. The findings emphasize the need for sustainable land use planning, coastal zone management, and disaster-resilient infrastructure to reduce vulnerability in tsunami-prone regions like Car Nicobar. Proper integration of geospatial techniques in policy-making can support ecological conservation while ensuring socio-economic development and resilience against future natural hazards.

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