Evaluating the effects of natural disasters, human influence, and government development policies on the landscape dynamics of Little Andaman, India

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Abstract

The Little Andaman Island face exploitation masked as development through the implementation of policies and schemes, which ultimately deplete and degrade its natural resources. Additionally, the island is also susceptible to frequent natural disasters and the adverse effects of climate change, compounding environmental challenges. The main aim of this study was to assess the dynamic changes in the landscape of Little Andaman during the years 1976, 1989, 2010, 2014, and 2022 using satellite data. Thematic maps of the area were generated using visual interpretation techniques. The study revealed that the dominant land cover in Little Andaman was forests, which gradually decreased from 622.79 km^2 in 1976 to 579.6 km^2 in 2022, resulting in an overall loss of 43.1 km^2 over 47 years. On the other hand, settlements, including built-up areas and agriculture, nearly doubled in size from 18.9 km^2 in 1976 to 36.60 km^2 in 2022. Mangroves, in contrast, exhibited stable coverage, with an area of approximately 31 km^2 in 1976, showing minor fluctuations until 2022. Plantations experienced an increase from 19.37 km^2 in 1989 to 22.28 km^2 in 2022. Water bodies also expanded gradually, reaching 10.4 km^2 in 2010 and maintaining a consistent size until 2022. In the meantime, degraded forests and degraded mangroves showed minimal changes over the years. The study identified a range of factors contributing to these changes, with a particular focus on tsunamis, climate change, and government policies and schemes.

Introduction

A landscape encompasses a diverse assemblage of Land Use and Land Cover (LULC) elements within a specific region, which includes both natural and human-modified features over time. Monitoring and assessing LULC Changes (LULCC) are crucial for effective management at a regional level (Vasanthawada et al. 2023). The LULC of an area experiences significant transformations due to a variety of anthropogenic and natural factors (Prasad et al. 2009). These LULCC reflect the intricate relationship between human activities and the natural environment (Vani and Prasad 2020). Traditional methods of assessing temporal LULCC are laborious, expensive, and challenging to obtain past LULC maps for change assessment. However, geospatial tools like Remote Sensing (RS) and Geographic Information System (GIS) offer a cost-effective and accurate means of analysing spatio-temporal landscape LULCC (Prasad et al. 2017). Understanding long-term LULCC aids in developing a dynamic framework that integrates human and natural landscape elements for sustainable ecosystem management (Prasad et al. 2010).

Island landscapes also experience varying levels of LULCC, primarily driven by anthropogenic disturbances. The island ecosystem, characterized by limited resources, vulnerable species, and fragile habitats, is particularly susceptible to the impacts of human activities (Chi et al. 2021). Overexploitation of natural resources disrupt the delicate balance of the island ecosystem, leading to irreversible

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damage to biodiversity and overall ecological dynamics. Additionally, the effects of climate change are a formidable challenge to island ecosystems. Rising sea levels, more frequent and intense storms, earthquakes, tsunamis, and altered rainfall patterns cause extensive damage to coastal habitats, posing a significant threat to the survival of island ecosystems (Alongi 1997; Prasad et al. 2012). The cumulative pressure of human activities and the threat of natural disasters modify the landscape elements, notably resulting in reduced vegetation and an increase in built-up or settlement areas, displacing forests. Moreover, the availability of resources within islands is limited, and variations in climatic conditions lead to shoreline changes and sea-level rise, encroaching on island resources externally (Balzan et al. 2018; Mageswaran et al. 2021).

The rapid changes in fragile island ecosystems can be attributed, in part, to government policies, schemes, and development projects that fall under the umbrella of island development (Shao et al. 2017). Economic growth and development initiatives often result in habitat destruction and deforestation on islands, making way for agriculture, urbanization, and infrastructure development. Consequently, critical habitats for native species are lost (Prasad et al. 2010). Accelerated economic growth on islands drives higher resource demand, potentially causing overexploitation and ecological imbalances, risking native species and ecosystems (Otero et al. 2020; Cardillo et al. 2006; Millennium Ecosystem Assessment 2005).

Additionally, economic growth fosters trade and transportation, inadvertently facilitating the introduction of invasive species to islands (Russell et al. 2017). These invasive species can outcompete native flora and fauna, causing disruption in the ecosystem and a decline in biodiversity (Doherty et al. 2016). Tourism, often stimulated by economic growth, can have both positive and negative impacts on island ecosystems (Tális et al. 2022). While it can provide economic benefits, unchecked and unsustainable tourism can lead to increased human activity, construction, and waste generation, causing overcrowding, habitat destruction, disturbance to wildlife, and environmental degradation (Ruiz-Mallén et al. 2015; Lukman et al. 2022). Without proper regulations and management, tourism poses a threat to delicate island ecosystems and cultural heritage. Moreover, this can adversely affect the local population, including tribal communities (Liu and Lu 2014), raising concerns about resource availability and the well-being of current and future generations living in the region (Sekhsaria 2001).

A similar situation is evident in Little Andaman, part of the Andaman and Nicobar Islands (ANI), India. In the past, the island suffered from the impact of introducing red palm oil cultivation, leading to the exploitation of forest resources (Saswati 2014). Recently, discussions about the development of ANI have emerged, signaling the island ecosystem's preparation for megaprojects (Sekhsaria 2021). Specifically, the government proposed constructing an international airport, an international tourism complex (eco-tourism resorts), and a new harbour at Dugong Creek on Little Andaman. However, under the concept of development, these projects encroach upon the island's natural landscapes to expand infrastructure and cater to tourists, visitors, and business growth, prioritizing economic gains over environmental preservation (Yang et al. 2020). Tourism has led to pollution from plastic waste and camping activities on sea turtle nesting beaches, disrupting their habitats on Little Andaman (Andrews et al. 2001). The consequences of these development activities directly deplete the island's existing resources and indirectly impact neighbouring ecosystems, ultimately jeopardizing their survival (Zhang and Xio 2020, Zhang et al. 2021).

In this context, the current study emphasizes the importance of understanding the dwindling temporal landscape dynamics of Little Andaman, caused by human interference, natural disasters, and government policies and schemes, both implemented and proposed. Additionally, the study examines their impact on the population of the Onge tribe. The study employs historical satellite imagery to observe landscape transformations and analyses the socio-economic factors responsible for such changes.

Study area

Before 2006, Little Andaman was considered a part of the former Port Blair tehsil. However, on the 17th of August 2006, the Andaman & Nicobar Administration declared Little Andaman as a distinct tehsil (Cgwb.gov.in n.d.). Little Andaman, located between 10°30′–10°56′N latitude and 92°28′–92°35′E longitude, is one of the prominent islands of the ANI (Fig. 1). Positioned to the south of Port Blair, the capital of ANI, the island spans approximately 12 km in width and 30 km in length, with a coastline area of 110 km. The reported area of the island varies slightly between 686 km^2 according to present study and 706 km^2 as per ANI administration records. It is isolated from the Great Andaman group by the Duncan Passage and from the Nicobar group by the 10° Channel (Anonymous 2003). Hut Bay, also referred to as Hut Bay Port Blair, serves as the administrative headquarters of Little Andaman Island. As the most developed region on the island, it functions as the primary administrative and commercial hub. Little Andaman is home to two ports, namely Hut Bay and Dugong Creek. Little Andaman comprises 16 inhabited and 3 uninhabited villages, covering an area of 34 km^2, with a total population of 18,823 (9964 males and 8859 females) (Census 2011).

Fig. 1 Location map of study area, showing megaproject development sites
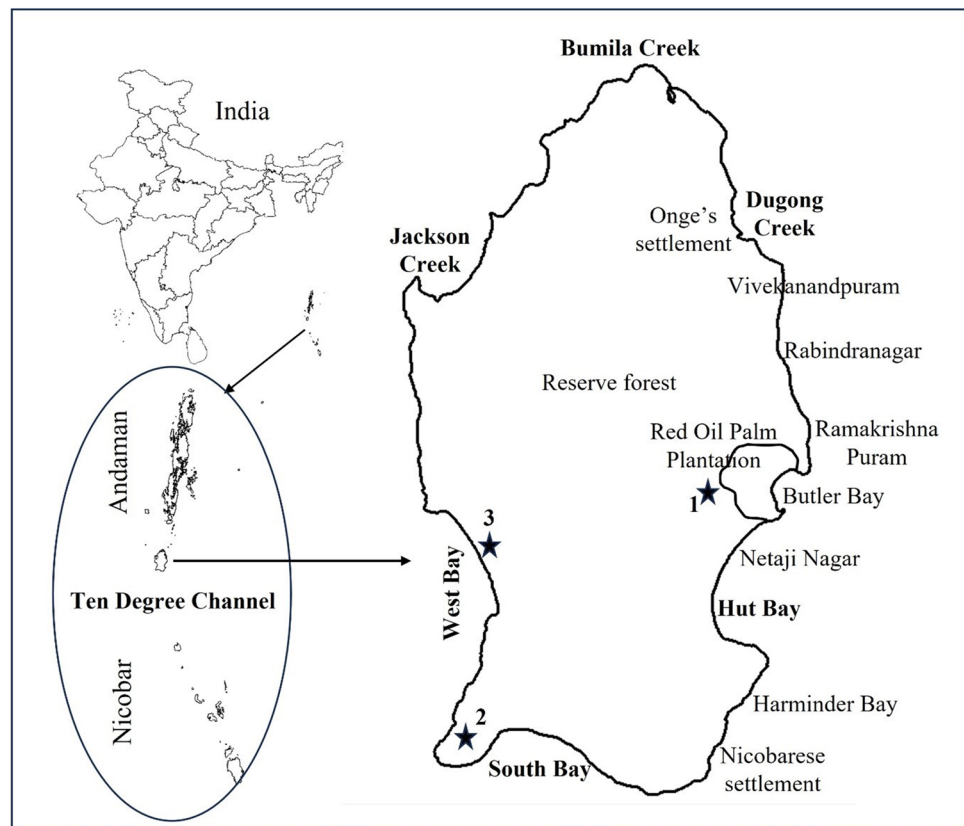
Zone 1: Financial District and Aerocity   Zone 2: Leisure Zone and Tourism   Zone 3: Nature Zone

Major settlement locations on the island include Hut Bay, Vivekanadapuram, Rabindranagar, Ramakrishnapuram, and Netaji Nagar (And.nic.in n.d.).

Little Andaman Island features a humid tropical climate and is prone to heavy rainfall and cyclones. It lacks significant drainage systems but has potential springs (Cgwb.gov.in n.d.). Unique wetland ecosystems on the island include freshwater streams, saline marshes, peat bogs, and grassy marshes (Andrews 2000; Andrews and Shanker 2002). Its geological composition includes dark-bluish-grey calcareous mudstone known as the Hut Bay Formation (Srinivasan 1975) and Neogene-age chalk and limestone formations referred to as the Archipelago Group (Bandopadhyay and Carter 2017). The central and southern regions are hilly, reaching elevations of up to 156 m above sea level (Sekhsaria 2001) and are mostly covered with tropical evergreen forests, providing a habitat for diverse wildlife. The soils in the area originate from sedimentary rocks such as Limestone, Coral sand, and Mudstone and have excellent drainage capabilities with high permeability. They are texturally categorized as sandy, loamy sand, and sandy loam (Cgwb.gov.in n.d.). Frequently cultivated crops and plantations on the island comprise paddy, red oil palm, various vegetables, coconut, arecanut, and a variety of fruits.

The island's predominant vegetation comprises tropical evergreen and semi-evergreen forests, moist deciduous forests, mangroves, and littoral forests (Anonymous 2003). Rasingam and Parthasarathy (2009) identified a total of 186 tree species, including 23 endemic species. They observed *Terminalia bialata, Tetrameles nudiflora, Pterocymbium tinctorium, Gyrocarpus americanus* and *Bombax insigne* as most dominant species of the island. The survey of Goutham-Bharathi et al. (2014) reported a total of 20 mangrove species. Little Andaman is also home to a diverse animal life with several endemic and endangered species, such as the Andaman wild pig and Andaman horseshoe bat. The avian population is also noteworthy, with approximately 185 bird species (Avibase.bsc-eoc.org n.d.) hosting a total of 34 endemic bird taxa, comprising both species and subspecies. Further the island is the last stronghold for the Andaman Teal and various other wetland birds (Andrews and Shanker 2002). Under the Wildlife Protection Act of 1972, specific portions of Little Andaman's Forest, including the 33 km^2 Little Andaman Wild Pig Sanctuary, have been designated as protected areas. Furthermore, in accordance with the same act, the ANI administration has enacted a comprehensive management plan to preserve and protect leatherback turtles (Thomas 2021).

The Onges tribe

In addition to settlers, the island is home to tribal communities, the Onge tribe mainly in Dugong Creek and South Bay, and the Nicobarese in Harminder Bay (Mahapatra et al. 2019). The indigenous Onge community has inhabited Little Andaman Island for generations, profoundly influencing its cultural and social biogeography (Portman 1899). Originally residing in three distinct areas on the island – Dugong Creek, Jackson Creek, and South Bay – government initiatives, driven by colonization and a desire to assist the Onge, led to their relocation to Dugong Creek in 1976–1977 and South Bay in 1980 (Mann 1978). Their traditional knowledge and practices are deeply intertwined with the island's natural resources and ecosystems. However, their population has dwindled to around 120 individuals (Sekhsaria 2021), and as one of India's PVTG (Particularly Vulnerable Tribal Groups), the Onge face significant challenges to their traditional way of life and cultural heritage (Ministry of Tribal Affairs 2015). Their economy primarily relies on marine and forest resources, including fish, dugongs, turtles, and forest-based food sources (Sarkar 1974). Yet, coconut cultivation, rehabilitation, and settlement efforts have made many of their traditional livelihoods obsolete (Gupta 2016). Given their limited access to infrastructure and resources, the long-term recovery and rehabilitation of the Onge community pose major challenges (Bhattacharyya 2006).

Materials and methods

The study aimed to trace the historical landscape dynamics of Little Andaman using Landsat satellite datasets for the years 1976, 1989, 2010, 2014, and 2022, obtained from the USGS (Table 1). Figure 2 illustrates the approach used for mapping the LULC of Little Andaman. All datasets, except for 1976, were acquired at 30 m spatial resolution and were checked for geometric and radiometric accuracy. The 1976 satellite imagery exhibited geometrical distortions, which were rectified using the 2022 satellite data. The study area

was extracted from the satellite images for different periods using a vector boundary. For each year, a false colour composite (FCC) was created using green, red, and infrared (NIR) bands. This data was further used to generate historical LULC maps through visual interpretation. Before interpretation, the data was subjected to an image enhancement process to enhance visual discrimination of features within the satellite data. An interpretation key was prepared, incorporating visual interpretation elements such as tone, texture, shape, pattern, location and association, to delineate the LULC classes of Little Andaman (Fig. 3). The thematic classes delineated are forest, settlements (including agriculture), mangroves, plantations, degraded mangroves, degraded forest, and water bodies (Creeks, streams or Nala). Additionally, a literature review of previous studies using satellite data for Little Andaman was considered to familiarize with the LULC classes that might be encountered during interpretation. Time-stamped Google Earth images were also utilized as a surrogate for field observations to enhance the accuracy and reliability of the generated maps, aligning them with the real ground scenario. The 2022 data was initially interpreted and subsequently overlaid onto other satellite data, facilitating the creation of specific LULC thematic maps through adjustments (editing-adding or deleting polygon boundary) made to the 2022 LULC layer.

The study refrained from employing a digital classification approach using supervised algorithms for two key reasons. Firstly, most previous studies on Little Andaman utilized visual interpretation, making it a preferable option to correlate the current findings with those studies. Secondly, digital classification approaches can lead to misclassification due to spectral overlap, though manual recoding (a form of visual correction) of error-prone locations can improve accuracy. Sophisticated advanced classifiers in digital classification have the potential to misclassify features entirely. For example, the study conducted by (Kolli et al. 2022) on the ANI using the Random Forest classifier provided false information about ANI's LULC. This serves as a classic example to demonstrate that even after creating LULC maps through digital classification, supervision is necessary to

Table 1 Satellite data used in the study

S.NO	Satellite/Sensor	Date of Acquisition	Spatial Resolution	Path/Row	Band Combination (FCC)
1	Landsat 1-5MSS	18/3/1976	60 m	144/053	NIR-6, Red-5, Green-4
2	Landsat 4–5 TM	17/12/1989	30 m	134/052	NIR-4, Red-3, Green-2
3	Landsat 4–5 TM	26/02/2010	30 m	134/053 134/052	NIR-4, Red-3, Green-2
4	Landsat 8–9 OLI/TIRS	09/02/2014	30 m	134/053	NIR-5, Red-4, Green-3
5	Landsat 8–9 OLI/TIRS	26/01/2022	30 m	144/053	NIR-5, Red-4, Green-3

OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor)

Fig. 2 LULC mapping methodology
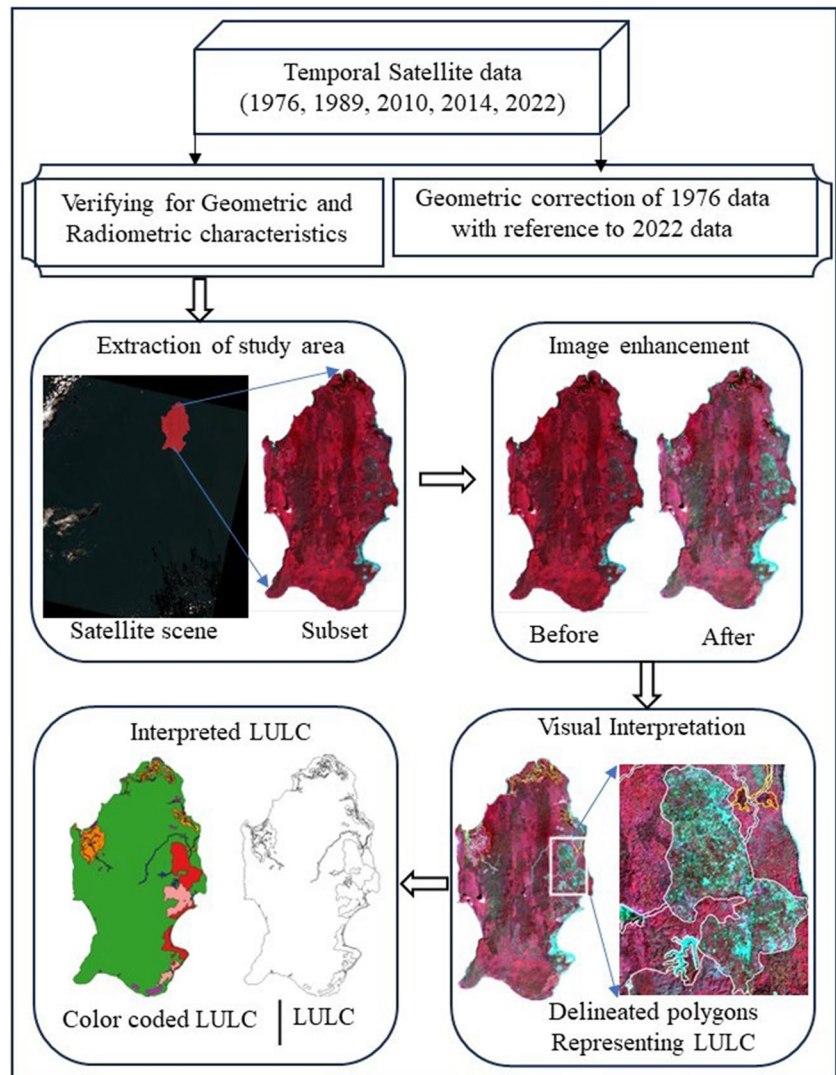
avoid incorrect outputs. Unfortunately, their study did not consider this crucial aspect and consequently yielded inaccurate LULC maps, that include Little Andaman too.

Results

Only a limited number of studies have been conducted on Little Andaman using remote sensing satellite imagery (Table 2). The current study compared its findings with those studies whose satellite image time stamps matched the period of the present study. The comparative table presenting data from current and previous studies (Table 2), revealed differences in the interpreted classes and their respective areas for Little Andaman. Over a span of 47 years, from 1976 to 2022, the study identified significant landscape dynamics in Little Andaman (Fig. 4). Although the changes in LULC features may seem small in terms of area metrics, they hold great importance considering the extent of island's

area and the scaling pressure these islands are experiencing. By utilizing satellite data, the study was able to observe historical spatial changes, while a thorough review of the literature facilitated the identification of socio-economic drivers responsible for these spatial transformations. Over the past five-decades, Little Andaman has been encroached by outsiders for residential development, agriculture, timber harvesting activities and plantation projects.

Forest is the dominant land cover class in Little Andaman. The study observed a gradual decline in forest extent from 622.79 km^2 in 1976 to 579.6 km^2 in 2022, indicating an overall loss of 43.1 km^2 over a period of 47 years, at an average rate of 0.91 km^2 per year. The most significant change in forest cover was observed between 1976 and 2010, with an average decrease of approximately 20 km^2. However, from 2010 to 2022, the change was insignificant, suggesting minimal human interference on forest ecosystems. The observed change in forest area is ascribed to a combination of anthropogenic logging activities,

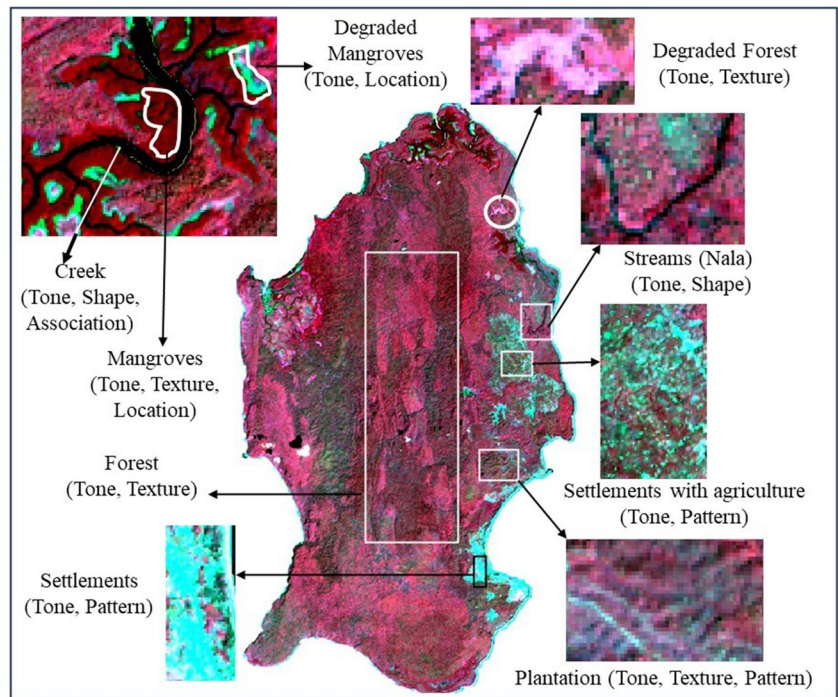**Fig. 3** Visual Interpretation Key Employed for LULC Mapping

**Table 2** Comparative LULC metrics (km 2) of Little Andaman

Years	Studied by	Forest	Settlements	Mangroves	Plantation	Waterbodies	Degraded forest	Degraded Mangroves
1976	Current Study (CS)	622.79	18.9	31	-	8.38	4.12	1.6
1976	Mahapatra et al. 2019	623.65	16.54	38.36	-	5.00	-	-
1989	**CS**	**599.42**	**21.59**	**31.5**	**19.37**	**8.5**	**4.5**	**1.8**
1989	Mahapatra et al. 2019	617.48	20.97	39.58	-	5.84	-	-
2001	Anonymous 2003	569.67	30.98	38.98	17.96	5.86	9.73	1.32
2003	Shankar et al. 2013	612.75	41.61	52.95	0.48	-	-	1.42
2005	Mahapatra et al. 2019	600.13	36.95	39.44	-	5.70	-	-
2005	Shankar et al. 2013	610.60	43.71	0.71	0.48	-	-	1.42
2010	**CS**	**579.9**	**36.07**	**31**	**21.8**	**10.4**	**4.5**	**2.3**
2010	Shankar et al. 2013	604.10	50.21	31.87	0.48	-	-	4.94
2014	**CS**	**579.8**	**36.56**	**31.5**	**22.04**	**10.34**	**4.63**	**2.06**
2017	Mahapatra 2019	593.0	42.58	42.36	-	5.75	-	-
2018	Mageswaran et al. 2021	584.14	32.20	39.33	21.11	4.68	4.43	1.96
2022	**CS**	**579.6**	**36.6**	**32.1**	**22.28**	**10.27**	**4.53**	**1.5**

Bold entries refer to the current study observations

government schemes, and the impact of the 2004 tsunami. Comparing the forest area findings of the current study with Mahapatra et al. (2019) study on Little Andaman, both studies reported similar metrics for 1976, with an area of 622.79 km^2 and 623 km^2, respectively. However, for the 2010 period, the current study observed 579.9 km^2, while Shankar et al. (2013) reported an area of 604 km^2, resulting in a net difference of 24.1 km^2 between the two studies.

The settlement class, comprising built-up areas, agriculture, roads, and other human-made features, is prominent on the eastern side of the island. It covered an area of 18.9 km^2 in 1976 and gradually expanded to 21.59 km^2 in 1989, 36 km^2 in 2010, 36.56 km^2 in 2014, and 36.60 km^2 in 2022. Over the span of 47 years, the settlement class almost doubled, with a net difference of 17.7 km^2 from 1976 to 2022. The major expansion of this class occurred between

Fig. 4 Spatio-temporal LULC maps of Little Andaman depicting landscape dynamics
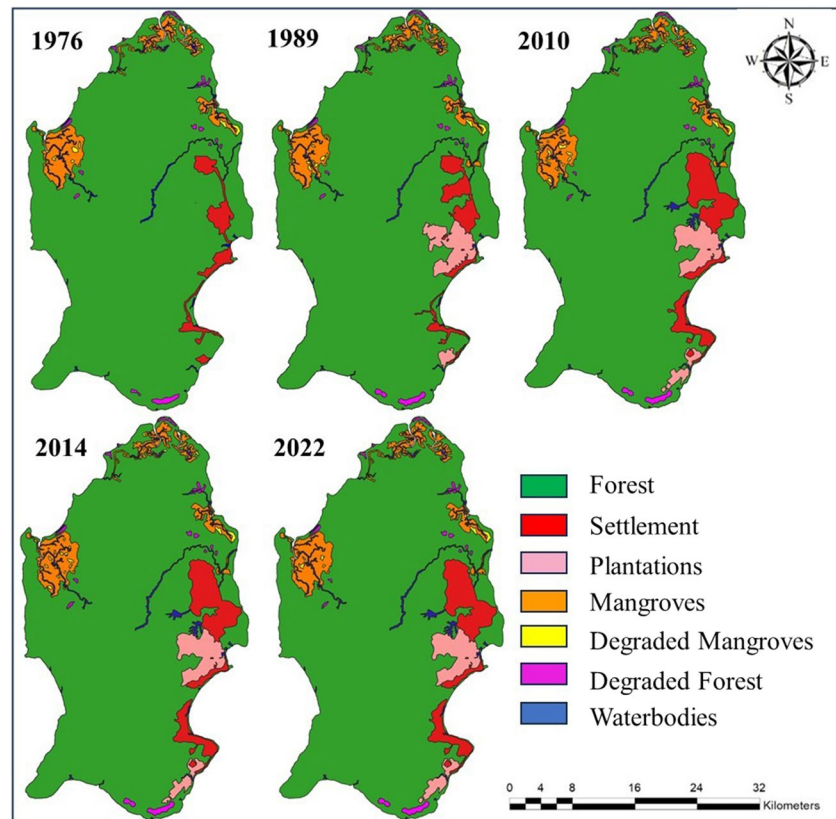
1976 and 2010, while after 2010, the change observed was minimal. The current study's estimation for 1989 (21.59 km^2) aligns with Mahapatra et al. (2019) observation of 20.97 km^2 for the same period. However, for 1976, the current study's area estimation of 18.9 km^2 slightly differs from Mahapatra et al. (2019) 16.54 km^2. Moreover, the estimation varies from Shankar et al. (2013) observation of 50.21 km^2 in 2010, showing a difference of 14.21 km^2 from the current study's estimation (36 km^2). The built-up area expanded due to population growth, infrastructure development, permanent tsunami shelters, and tourism growth (Mahapatra et al. 2019).

Mangroves are predominantly located in the northern region of Little Andaman, near Jackson Creek in the west and Dugong Creek on the eastern side of the island. The study revealed relatively steady mangrove cover in Little Andaman, with minor fluctuations over the years. The mangrove area was approximately 31 km^2 in 1976, experiencing a subtle increase to 31.5 km^2 in 1989, followed by a slight drop to 31 km^2 in 2010. Thereafter, it increased again to 31.5 km^2 in 2014 and further to 32.1 km^2 in 2022. Overall, an increasing trend in the mangrove class was observed. When comparing the current study with that of Mahapatra et al. (2019) for the mangrove class in 1976 and 1989, some discrepancies were noted, with the current study estimating 38.36 km^2 and 39.58 km^2, respectively.

However, both studies showed a similar incremental trend from 1976 to 1989. Conversely, the current study's estimation for the year 2010 aligns with Shankar et al. (2013) observation of 31.87 km^2. Compared to other studies, Shankar et al. (2013) reported the highest mangrove area in 2003, accounting to 52.95 km^2. (Table 2). Unlike earlier studies, Kolli et al. (2022) reported distinctive observations for the Little Andaman mangrove class. In 2000, they noted grasslands in Jackson Creek and mangroves within the reserve forest. By 2010, Jackson Creek's grassland had been replaced by mangroves, and the reserve forest's mangroves had become evergreen forests. Finally, in 2020, they reclassified Jackson Creek's mangroves as agricultural land and the grassland. Using advanced classifiers like Random Forest without proper field knowledge and supervision can result in incorrect classifications potentially generating pseudo LULCC and misleading future researchers.

The island's climate, characterized by an annual rainfall of 3500–4000 mm and temperatures ranging between 22 and 35 °C, is favourable for the cultivation of Red Oil Palm (ROP) plantations (Kharti 2002). No plantation class was observed in the 1976 data. However, the plantation cover demonstrated an increasing trend from 19.37 km^2 in 1989 to 22.28 km^2 in 2022, showing a net rise of 2.91 km^2. Mageswaran et al. (2021) reported an area of

21.11 km^2 in 2018, and with a four-year gap, the current study observed 22.28 km^2 in 2022, indicating a growth trend in plantation area. Sekhsaria (2021), identified an area of 15 km^2 under ROP plantation. Subtracting this from the 2022 estimate of 22.28 km² reveals that 7 km² falls into the category of other plantations.

Waterbodies in Little Andaman exhibited a gradual increasing trend, although the area expansion remained relatively low. The class covered around 8.38 km^2 in 1976, slightly increasing to 8.5 km^2 in 1989, and further reaching 10.4 km^2 in 2010, maintaining a similar extent until 2022. While Mahapatra et al. (2019) observations differ from the current estimations for 1976 and 1989, both studies show a similar incremental trend in the water bodies class, with areas of 5 km^2 and 5.84 km^2, respectively. Degraded forests showed variations, increasing from 4.1 km^2 in 1976 to 4.5 km^2 in 1989, remaining constant until 2010, then rising to 4.6 km^2 in 2014 and declining to 4.53 km^2 in 2022. Similarly, degraded mangroves displayed incremental changes from 1.6 km^2 in 1976 to 2.3 km^2 in 2010, followed by a decline to 2.06 km^2 in 2014 and further to 1.5 km^2 in 2022. The rise observed between 1976 and 2010 can be linked to the impact of the 2004 tsunami, while the subsequent fall may be ascribed to the natural regeneration of mangroves.

Discussion

The study provided a comprehensive analysis of LULCC in Little Andaman over the last 47 years, using spatial and temporal data from Landsat satellite imagery. The research identified areas most susceptible to LULCC, highlighting vulnerable regions. The findings revealed a decline in forest area alongside an increase in settlement and plantation classes. To counteract forest degradation and biodiversity loss resulting from illegal logging and poaching, various conservation measures have been implemented (Sekhsaria 2004). These conservation efforts are responses to past government policies that have impacted the island ecosystem, in addition to human interference, natural disasters and climate change effects. The following section focuses on examining the influence of various drivers on LULC changes, as well as their impact on the Onge tribe and island ecosystem of Little Andaman (Fig. 5).

Natural disasters -impact of tsunami and sea level rise

Compared to Dugong Creek, the South Bay camp was considerably more affected by the tsunami (Saswati 2014). The impact assessment of the tsunami on this island revealed a loss of 2.58 km^2 of forest vegetation, comprising dense (1.75

Fig. 5 Abstract of anthropogenic and natural drivers impacting the Little Andaman ecosystem (Dark lines indicate the impact of drivers)
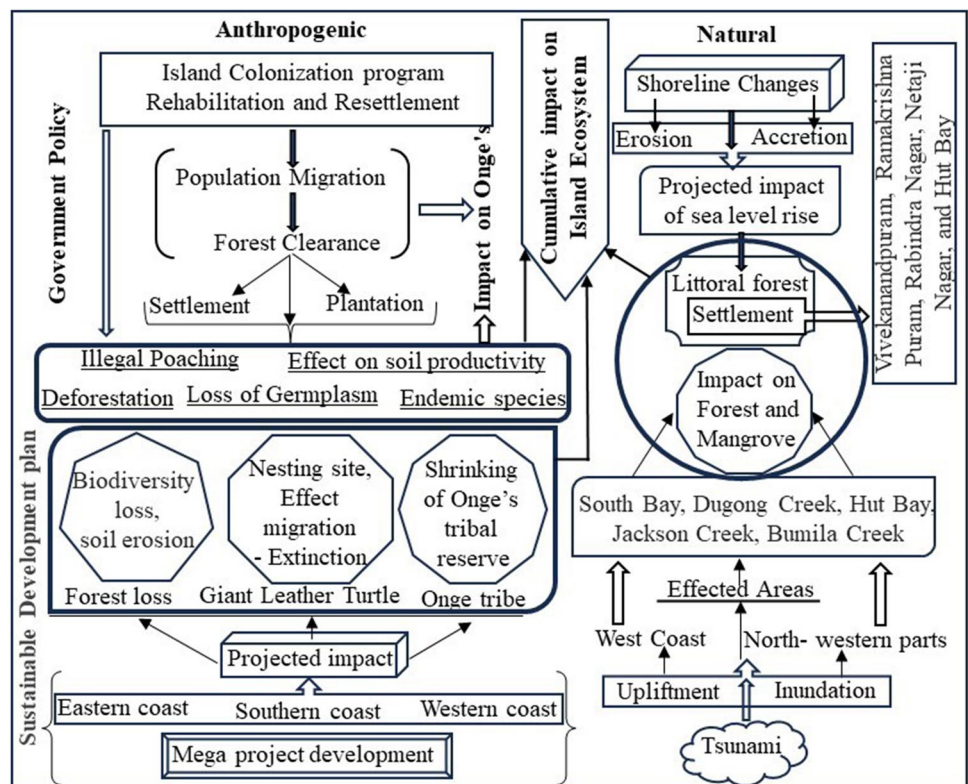
km^2) and open (0.83 km^2) categories (FSI 2005). Shankar et al. (2013) reported loss of 2.3 km^2 reserve forest area and submergence, damage, and degradation of 34 km^2, 17 km^2, and 1.4 km^2 of mangrove areas respectively. In the present study, the mangrove area remained stable during the observation period due to two main factors. Firstly, the study did not consider post-tsunami data. Secondly, over time, there might have been a regeneration process contributing to the consistent mangrove area. Several subsequent studies have been conducted to investigate the effects of the tsunami on inundation, upliftment, and submergence. Ramana Murthy et al. (2005) reported an inundation distance of 1200 m from the shore in Hut Bay. Iyyappan et al. (2018) confirmed this with a maximum inundation of around 1260 m, aligning with Ramana Murthy et al.'s (2005) findings. The study also identified highly affected areas, including Jackson Creek, Bumila Creek, and Dugong Creek on the island's western, northern, and northeastern sides. Bignami et al. (2005) observed surface changes and the uplift phenomenon caused by the tsunami. The use of satellite images before and after the disaster helped detail the inundation of the forested area in the north and western parts of the island by analysing differences in backscattered signals resulting from the tsunami-induced surface changes. However, the study did not quantify the extent of the damaged area. Chini et al. (2008) reported uplift along the west coast of Little Andaman, while Anu and Rajendran (2006) documented a 36 cm uplift.

Besides tsunamis, Little Andaman's shoreline is influenced by natural factors like waves, tides, currents, and storm surges. Mageswaran et al. (2021) analysed shoreline changes across three periods: –2004, 2004–2005, and 2005–2018. They found rates of shoreline migration ranging from − 8.8 to 7.7 m$^{−year}$ during 1976–2004, with an average of -0.27 m$^{−year}$. Eroding coasts averaged − 2.8 m$^{−year}$, while accreting coasts averaged 2.42 m$^{−year}$. Most coastal areas were stable (58.4 km), with erosion in some areas (39 km) and accretion in others (31.1 km). Notably, Dugong Creek, Vivekanandpur, Hut Bay, and South Bay experienced erosion. Mageswaran et al. (2021) projected the impact of sea level rise on Little Andaman, revealing significant damage to various coastal features, including forests, settlements, and plantations. With a 1-meter sea level rise, approximately 44.84% (1024 ha) of forest land, including degraded and reserve forests, would be submerged. A 3-meter and 5-meter rise would increase this to 68.6% (1988.4 ha) and 80.26% (2912.7 ha), respectively. Littoral forests within 150–200 m from the shore are particularly threatened. Settlements like Vivekanandpuram, Ramakrishna Puram, Rabindra Nagar, Netaji Nagar, and Hut Bay, especially the latter two due to their topography and population density, would also face significant damage from rising sea levels. In conclusion, their findings highlight the vulnerability of Little Andaman's coastal areas to various flooding events, posing threats to ecosystems and human communities, compounded by tsunamis and shoreline changes.

Human interference, government policies and schemes

Plantation and timber extraction - impacts

In detail, Sekhsaria (2001, 2004) and Saswati (2014) extensively documented the methods and practices of forest exploitation on these islands. The anthropogenic degradation of the island commenced in approximately with a government-led colonization program that promoted population migration from mainland India, including refugees from Bangladesh, as well as repatriates from Sri Lanka and Myanmar. Under the 'Accelerated Development Programme for Andaman and Nicobar,' an 'Inter Departmental Team' established by the Ministry of Rehabilitation (Anonymous 1965) prioritized development efforts in Andaman archipelago, with a specific focus on Little Andaman. The selection of the island for a Rehabilitation and Resettlement (R and R) program was based on its substantial size, rich forest resources, and a small population, primarily composed of the Onge tribe (Sekhsaria 2001). In the rehabilitation efforts, five villages were established along a 28-km stretch of the island's eastern coast, including Hut Bay, Netaji Nagar, Rabindranagar, Ramkrishnapuram, and Vivekanandapuram (Bose 1994). To support the migrants, approximately half of the island's forests were cleared for settlements and various plantations like coconut and betel cultivation. Unfortunately, the government disregarded the island's legal status as a tribal reserve for the Onge people, as it had been denotified under the "Protection of Aboriginal Tribes Regulation 1956" by the ANI Administration in 1957 (Anonymous 1957) and designated as a "Reserve Forest" in 1963. Despite regulations stating no logging in the Onge's reserve areas, the Forest Corporation violated this rule by logging timber within the reserve (Sekhsaria 2001). These actions flagrantly violated the rights of the Onge tribe.

Plantation activities peaked on the island in 1970 with the establishment of a sawmill, resulting in extensive deforestation. The growing population on the island accelerated the degradation of forest resources and led to the poaching of wildlife, including the endemic Andaman wild pig and the sea mammal Dugong (Sekhsaria 2004). This destructive combination caused habitat loss and population declines in these species (Pande et al. 1991; Tambe and Acharya 1997). Logging also created pathways into the interior forests, enabling settlers to encroach and engage in illegal poaching. In 1972, about 20,000 ha (200 km^2), roughly 30% of the island, lost its tribal

reserve status (Reddy 1994; Andrews 2000). Large-scale deforestation ensued, placing the Onge tribe in competition with settlers for wild boar and fish resources. While the Onge continued hunting and honey collection in the remaining forests, they became dependent on rice, lentils, and other essentials provided by the Andaman authorities (Gupta 2016).

The Andaman and Nicobar Forest and Plantation and Development Corporation (ANFPDC; Anonymous 1976) introduced ROP cultivation alongside timber extraction by both government and private traders. ROP cultivation commenced in 1975-76 with 160 ha (1.6 km²) and expanded to 1,593 ha (15.93 km²) by 1985-86, primarily for Crude Palm Oil production (Sekhsaria 2004). There were proposals to further extend the plantation to 2,400 ha (24 km²) and 5,000 ha (50 km²) in two phases, but in 1986, the government imposed a ban on such expansion (Bhatee 1985-86). This decision was made to preserve the island's tropical rainforests, recognized as critical gene pool reserves and complex ecosystems (Degen and Sebbenn 2014). Clearing extensive forest areas for ROP plantation would result in the loss of this valuable germplasm source (Koh and Wilcove 2008; Fitzherbert et al. 2008). Considering the labour-intensive nature of ROP cultivation at 3.5 men ha^{-1}, which exceeds the island's carrying capacity, the Indian government decided to cease any further expansion of oil palm plantations in ANI (Kharti 2002).

The Central Agricultural Research Institute (CARI) in Port Blair found that transitioning from tropical rainforest to plantation takes about 15 years for soil properties to stabilize. This shift to monoculture plantations negatively impacts soil productivity, fertility, disrupts hydrological cycles, and encourages the introduction of exotic species and pests. In 1996, CARI noted a rise in rodents in Little Andaman's plantation areas. In response to NGO petitions regarding palm oil plantations in Little Andaman, the Supreme Court formed an expert committee in 2002, leading to a ban on commercial and monoculture oil palm plantations in the ANI. Later, NITI (National Institution for Transforming India) Aayog requested ANI to seek the Supreme Court's permission to lift the ban, presenting a study by the Indian Council of Agricultural Research-Indian Institute of Oil Palm Research in December 2018. The court pursued the opinion of the Indian Council of Forestry Research and Education (ICFRE) in January 2020, which recommended avoiding oil palm cultivation in biodiversity-rich areas pending detailed ecological impact studies. However, despite the absence of comprehensive ICFRE research, the Union government approved the mission, raising concerns about political motivations over environmental and expert considerations (Source: Down To Earth 2019).

Mega project development

The sustainable development plan for Little Andaman Island proposes three zones. (Sekhsaria, 2021; Fig. 1). Zone 1 (102 km²) along the eastern coast envisions an Aerocity featuring an international airport to drive district development. Zone 2 (85 km²) on the southern coast lays out plans for a Leisure Zone and Tourism Special Economic Zone, complete with casinos, theme parks, and beach hotels. Zone 3 (52 km²) situated on the western coast strives to establish a Nature Zone, offering luxury resorts, hotels, and a private charter flight airstrip. To enhance connectivity between these zones, the plan includes the construction of a 100-km Greenfield coastal ring road, complemented by a mass rapid transit network with conveniently placed stations. However, the expansive project, covering 35% of the island and affecting 107 km of coastline, raises concerns for the Onge tribe, biodiversity, and Giant Leatherback Turtle nesting sites. It would shrink the Onge Tribal Reserve by 31%, posing uncertainties for their relocation and preservation of traditions. Furthermore, the project's substantial forest land diversion threatens irreversible harm to the island's forests, potentially resulting in over 2 million tree losses, topsoil erosion, decreased rainfall, and adverse effects on arable soil. Additionally, significant tree removal would contribute to carbon emissions and carbon stock losses, estimated at 2,996.286 tonnes across various forest types. These developments exacerbate the effects of climate change, impacting the island's ecosystems (Source: Antiaero.org n.d.; Veron et al. 2019). The development plan poses a threat to leatherback turtles nesting sites, particularly South Bay and West Bay, which are critical high-intensity nesting areas crucial for their survival (Andrews et al. 2006; Swaminathan et al. 2016, 2019). These sites hold official recognition as "Important Marine Turtles Habitats in India" in the National Marine Turtle Action Plan (MoEFCC 2021). Implementing the proposed project carries the risk of further endangering Giant Leatherback Turtles, potentially disrupting their migratory routes and nesting patterns, and pushing them closer to extinction (Thomas 2021). The development lacks transparency, with the 'Sustainable Development of Little Andaman - Vision Document' undisclosed and no environmental impact assessment. De-notifications and rule amendments have removed protections, enabling mega-projects on Little Andaman Island (Source: Ejatlas.org n.d.).

Conclusions

The study documented significant landscape changes on the island, with varying levels of agreement with the work of other researchers. These changes consistently indicated

a decline in forest cover and an increase in settlements and plantations, primarily influenced by government policies. A major contributor to these changes was the government's rehabilitation scheme, inadvertently leading to resource degradation as migrants encroached upon forest areas. The government also prioritized economic gains through ROP cultivation and timber extraction, even encroaching on the lands of the Onges tribe. Natural disasters and climate change further exacerbated resource, population, and livelihood challenges on the island. Proposed actions, such as lifting the ROP cultivation ban and implementing mega development projects, pose significant threats to the delicate island ecosystem, endangering flora, fauna, and the Onges tribe. Throughout these changes, the Onges population suffered disproportionately due to government policies. While the Onges have coping mechanisms for natural disasters, addressing the adverse effects of government decisions remains a challenge. Preserving the unique cultural and ecological heritage of the Onge people necessitates thoughtful and sustainable solutions to ensure their well-being and continuity in a changing environment.

The proposed developmental plan threatens the island's ecological integrity and questions the long-term sustainability of the infrastructure, especially considering the potential impacts of disasters like tsunamis and climate change. Prior studies have noted shoreline changes, inundation, and upliftment in various regions of Little Andaman. The government's focus on economic interests at the expense of ecological sustainability raises concerns about negative environmental impacts and ecosystem balance. To protect the island's ecological integrity and enhance resilience to natural hazards and climate change, sustainable development practices must prioritize conservation and responsible environmental management.

Declarations

Ethics approval Not applicable.

Consent Authors agreed with the content and gave explicit consent to submit and that they obtained consent from the responsible authorities at the institute/organization where the work has been carried out before the work is submitted.

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