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The cover image shows a copy of the 1987 UN report "Our Common Future – The report of the world Commission on Environment and Developments". The picture has been taken in TeMA Lab in July 2023. On the bottom, there is a collage made up of four pictures of recent climate disasters (Source: Google images)

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Remote sensing investigation of spatiotemporal land-use changes

A case study of Batticaloa town in Sri Lanka from 1979 to 2021

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Abstract

Rapid and haphazard urbanization has disastrous environmental and socio-economic consequences. The increase of unofficial habitation characterizes urbanization in Batticaloa town. Urban land use and cover changes require research to plan and ensure long-term growth. This study employed geographic information systems and Landsat imagery from 1979, 2000, and 2021 to look at regional and temporal variations in Batticaloa's land use cover. A support vector machine and supervised classification constructed the land use cover maps. The transition matrices produced from the classified map were further investigated to find the essential change processes for prioritizing planning, and during the 42 years investigated, built-up, including residential, commercial, and public facilities, increased in a similar vein (i.e., mangroves, paddyland, vegetation-covered areas, and shrubs). Land use cover modifications happened more quickly between 2000 and 2021 than between 1979 and 2000. The analysis found that only one land-use category, net built-up area changes, grew by 8.2%, and the average yearly change was 0.22%. By 21.9%, paddy land area substantially increased. Bare lands rose 4.45%, and thick woods fell 21.37%. These data show built-up areas frequently targeted bare terrain. This research laid the groundwork for long-term urban planning and development in Batticaloa Town.

Keywords

Land use; Land cover, Remote sensing; GIS; Urbanization.

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1. Introduction

Urbanization represents the anthropological activities influencing land use that the immense pressure from population growth has endangered. Global and regional environmental sustainability is affected by urbanization (Grimm et al., 2008). anthropogenic activities have severely threatened sustainable resource use, where urbanization has played a significant role. The United Nations (2019) predicts that by 2050, urbanization will make up 68 per cent of the world's population, a rise from 55 per cent in 2021; over 90% of this increased population will be in Asia, particularly in small and medium cities. In 2021, only 42.9 per cent of Asians lived in towns, predicted to climb to 56.5 per cent by 2050. A complete land use/land cover (LULC) analysis is required to thoroughly examine environmental change and sustainability (Manandhar et al., 2009). Anthropogenic activities such as urbanization have increased, hastening LULC changes (Gunasinghe et al., 2021). All regions' interactions are unique, but most scholars agree that specific demographic, socio-political, economic, and environmental conditions drive most LULC changes (Masek et al., 2010; Addae & Oppelt, 2019). The paper argues that a more extensive use of remote sensing, coupled with GIS analysis, can provide valuable insights and tools for enhancing land use policies. Remote sensing technologies like satellite imagery can capture detailed information about land cover, land use patterns, and changes over time. GIS analysis allows for the integrating and interpreting spatial data, enabling a better understanding of land dynamics and supporting evidence-based decision-making. Fistola (2021) said that, Through the clever adoption of new technologies, it is possible to "see" and verify the transformation of the city in advance and take socially shared decisions.

In most cases, these elements interact. Since urban regions provide better economic and social opportunities than rural areas, many people move to the cities, fueling a surge in population that depletes natural resources for settlement and livelihood (Addae & Oppelt, 2019; Mwathunga & Donaldson, 2018). Many people are drawn to cities because of their economic and social advantages over rural areas, leading to rapid population growth and over-exploitation of natural resources for city settlement and life.

Advances in remote sensing have benefited LULC change research throughout the last four decades. Using remote sensing techniques, LULC changes can be tracked over time (Yang & Lo, 2010). Despite constraints such as spatial and spectral confusion in metropolitan regions, remote sensing is an excellent data source for LULC investigations. Land-use planning and urban management in developing nations rely heavily on analyses of urban land-use changes based on Landsat photos. Landsat data can be a valuable source of information not available from other sources. South Asia has a high population density and sociocultural diversity, making it an economically developing region (Dissanayake et al., 2017). This economically expanding region can also be unstable politically (Dissanayake et al., op. cit.). Combined with land use and climate variability, these factors probably played a significant role in the LULCC in the region (Mitra & Sharma, 2010). Despite ongoing political and social instability, limited historical documents in this region often hinder these studies, which can shed light on land-use change and its consequences. Sri Lanka faces a fundamental challenge in land cover change analysis because there has never been a large-scale study of LULCC. The ones available are very confined and restricted to temporal comparisons (Mapa et al., 2002; Perera & Tsuchiya, 2009; Subasinghe et al., 2016; Suthakar & Bui, 2008; Wickramaarachchi et al., 2013).

Despite this, the country's landscape changes due to socio-economic, political, and biophysical factors. In the late 1970s, adopting an open economic policy led to significant socio-economic and political changes. Following this were many initiatives, such as the Mahaweli River Basin Development Project (1980–2018), which implemented transportation and road improvement projects and irrigation-based agricultural development (Mapa et al., 2002; Näsström & Mattsson, 2011). In addition to the civil war, Sri Lanka was also afflicted by a civil war between 1980 and 2009. The northern and eastern parts of the country were severely damaged, and for some portions of the war, the entire country was negatively affected. (Athukorala et al., 2017). This period's LULC changes records are either missing or significantly limited. In 2009, the end of the 30-year civil war sparked a flurry of construction projects around the country. This dynamic terrain's LULC changes have yet to be studied and measured.

In 1978, Sri Lanka gained its democratic government system and has been experiencing progressive urbanization ever since. The country has become one of the fastest-growing nations in South Asia. Despite that, various research has been done on LULC changes in Sri Lanka (Athukorala et al., 2017; Masakorala & Dayawansa, 2015; Partheepan & Manobavan, 2008; Perera & Tsuchiya, 2009; Subasinghe et al., 2016; Wickramaarachchi et al., 2013), In Sri Lanka, studies on urban LULC change are few and far between; as a result, the concept of urbanization is mainly based on population data. Economic and environmental planning is hampered because lacking LULC change information leads to erroneous policy decisions (Masakorala & Dayawansa, 2015). Low-income nations like Sri Lanka prioritize urgent requirements like poverty reduction above long-term goals like sustaining a robust LULC system (Masakorala & Dayawansa, 2015; Mwathunga & Donaldson, 2018).

Batticaloa, the second-largest city in eastern Sri Lanka by population, has not yet been assessed for urban LULC status. The descriptive analysis of land use and land cover changes in Batticaloa aims to provide an overview of how various factors, such as economic growth, population growth, and political government instability, have influenced the transformation of the city's land over time. By examining these factors, we can gain insights into the dynamics of land use and land cover changes in Batticaloa. One significant driver of land use and land cover changes in Batticaloa is economic growth. As the city experiences economic development, there is often an increased demand for commercial and industrial spaces. This can lead to the conversion of agricultural or natural areas into built-up environments, such as factories, offices, and shopping centres. The growth of the population in Batticaloa can have a substantial impact on land use and land cover patterns. As the number of residents increases, a greater need for residential areas and associated infrastructure like housing, schools, and healthcare facilities exists. This can lead to the conversion of agricultural land or natural habitats into residential zones. Population growth may also drive the expansion of commercial and recreational spaces to meet the needs of the growing population, potentially resulting in the transformation of undeveloped land. Political government instability can also contribute to land use and land cover changes in Batticaloa. Uncertain political environments may lead to changes in land ownership, policy shifts, or infrastructure development project disruptions. These factors can influence land use patterns as investments and development activities may be delayed or redirected. Moreover, political instability may result in conflicts or displacements that can affect land cover, particularly in terms of land abandonment, informal settlements, or changes in land use due to security concerns. By integrating and analyzing these data sources, researchers can generate a comprehensive understanding of the land use and land cover changes in Batticaloa, attributing them to economic growth, population growth, and political government instability. This descriptive analysis can provide valuable insights for urban planning, resource management, and decision-making processes in the city and its surrounding region.

In addition, there is a need for more empirical evidence documenting changes in urban LULC across time. Therefore, this study aims to examine the evolution of Batticaloa's urban LULC from 1979 to 2021 using Landsat data to promote sustainable urban development. 1979 was selected as a starting year since Sri Lanka changed its democratic governing structure. The field verification is scheduled for 2021, so the end year was chosen for comparison, and 2000 was used for comparison as an interim year. The primary objectives of this study are as follows:

- to mitigate the adverse environmental and socio-economic impacts associated with rapid and unplanned urbanization;
- to analyze the patterns of urban land use and cover changes in Batticaloa town, with specific emphasis on the growth of unofficial habitation;

- to compare and assess the modifications in land use cover between two distinct time periods, namely 1979-2000 and 2000-2021, to determine the change rate;
- to investigate the transition matrices generated from the classified maps, aiming to identify the significant processes of change. These findings will aid in prioritizing planning efforts.

A study has been done to determine how urbanization has influenced LULC in Batticaloa Town from 1979 to 2021. Because of the following three reasons this study is important: Firstly, it shows anthropological progressions in municipal landscapes and their relations; Secondly, the generated data can help manage the increasing pressure of anthropological activities and municipal development on the city area; and lastly, the findings can be used to identifying future land uses and setting policy priorities in support of inclusive and equitable urban development. This initiative will benefit Batticaloa Town residents as well as the environment.

2. Literature Review

The phrase 'land usage' typically refers to the alterations made to the earth's surface as a result of an increase in human activity. The term "land cover" refers to the physical manifestation of the earth's surface, water distribution, soil, plant, and urban area layout. The use of land and land cover are two independent ideas, yet they are connected. Land cover and land use variation information is vital in domestic, local, and general administration and planning. Due to a lack of knowledge of land use and land cover differences, the planning and organization of environmental initiatives and activities are frequently disrupted (Fahad et al., 2020).

According to Fahad et al. (2020), changes and variations in the land cover occur gradually, but occasionally they can occur rapidly and unexpectedly due to human activities. As a result of the destruction of a region's nature and vegetation, land use and land cover changes may affect the ecosystem. Variations in land cover and land use are among the most significant human activities altering hydrology. Remote sensing has advantages for mapping land cover and land use and analyzing essential changes. The primary benefit of remote sensing systems is the capacity for repeated coverage, which is required for global investigations of change detection. Remote sensing can detect changes in land cover and land use and monitor the consequences of human and natural activity. Among the most significant advantages of remote sensing are cost and time savings. Land cover and land use products are utilized for global mapping, identification modification, and landscape design. Image classification using remote sensing combines image processing and image classification algorithms (2020).

Given the importance of land surface cover and use and their changes associated with urbanization, satellite remote sensing can play an important role in providing relevant baseline geospatial information on land use land cover (LCLU) and its historical change delineation, as well as the surface temperature field during satellite overpasses. The Landsat series of satellite sensors, specifically the Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) have been indispensable image data sources. Visible/infrared data from satellites such as Landsat can be interpreted to provide quantitative parameterizations of land cover and usage and thermal images of areas of interest (Zhang & Sun, 2019).

According to Zhang and Sun (2019), the spatial resolution of Landsat image data (30 m in the visible/infrared and 60–120 m in the thermal infrared parts of the spectrum) is insufficient to resolve the intricate details of the majority of urban areas, posing one of the most significant obstacles to interpreting Landsat image data. Consequently, most image pixels contain contributions from diverse surface covers, such as artificial impervious surfaces such as roads and building roofs, as well as herbaceous and forest plants. Numerous spectral un-mixing techniques to extract fractional components, such as V-I-S and endmember analyses (e.g. Powell et al., 2007) and percentage estimates of impervious surface and forest cover, have been developed in the past to address the 30-metre resolution limitation problem (Guindon et al., 2004).

According to international data, by 2050, the global urban population will increase by up to 68 per cent. The United Nations (UN) forecasts that Asian and African nations will urbanize more rapidly than nations on other continents (United Nations, 2018). Rapid urbanization will bring severe environmental and socio-economic challenges in the future, including land degradation, the loss of urban ecosystem services, urban heat islands, air pollution, flooding, health, urban poverty, crime and violence, and traffic congestion (Son et al., 2017). Industrialization and urbanization are very important determinants of the rate of agricultural land conversion into non - agricultural uses (Olaniyi et al., 2021). Consequently, sustainable urban development has emerged as a topic of interest for research in a diverse range of academic disciplines, including geography, engineering, economics, politics, and sociology. Despite the many advantages of urbanization, sustainable urban development is seen as a method for preventing, lessening, and minimizing the negative consequences of urbanization on the environment and the socio-economic system (i.e. social and economic improvement of living conditions). So, understanding the spatial-temporal diversity of urbanization patterns will make it easier to undertake sustainable urban planning in developing nations.

Many researchers have focused on urbanization patterns during the preceding two decades. Quantitative studies of urbanization have improved, even though there is a lack of spatial data to work with. This is especially true in the developing nations of Asia and Africa. These developing nations can overcome their restrictions by utilizing the data gathered from remote sensing and the techniques provided by the geographic information system (GIS) (Ndzabandzaba, 2015). For data extraction, remote sensing can utilize various geographical and temporal resolutions. This allows for collecting information on land use and cover, the ground surface temperature, population density, and energy consumption. The patterns of urbanization may be analysed using GIS techniques, as can the patterns of urbanization in the future. Consequently, the relationship between urbanization and sustainable urban development has emerged as a primary concern in constructing sustainable cities at all levels, including local, regional, and worldwide (Murayama et al., 2021).

3. Data and Methods

3.1 Description of the Study Area

Batticaloa city is located between 7°42'02"N and 7°43'60"N, and 81°40'62"E and 81°42'60"E. The Batticaloa lagoon surrounds it on three sides. It has a total size of 75.09 square kilometres. Batticaloa Town has a dry climate with hot summers, with a mean minimum and maximum of 30.7oC and 37oC, respectively. Monsoon winds provide rain to the region from November through February. Between 1900 and 2006, annual rainfall averaged 1645 mm. (Partheepan & Manobavan, 2009). A "sandwich pattern" of ethnic populations exists in Batticaloa, with 91 per cent Tamils, 5 per cent Muslims, 0.14 per cent Sinhalese, and 3.86 per cent others. (Department of Census and Statistics 2022). Batticaloa was a small town in Sri Lanka in 1979, with 52,452 residents; by 2021, Batticaloa had grown to 93,058 (Department of Census and Statistics, 2020). It has a population density of 1,938 persons per square kilometre, accounting for about 16 per cent of the district's population. (Partheepan & Manobavan, 2009).

Approximately 4311.87 hectares of the land area of Batticaloa city are devoted to the different purposes of residential, agricultural, commercial, wetlands, water bodies, scrub, and others (Fig.1). Due to the lack of sewage infrastructure in many unauthorized/regularized communities, sewage is discharged into these bodies of water, although they were built to transport rainwater (Partheepan & Manobavan, 2008). Because of its outstanding tertiary operations, Batticaloa is a vibrant regional development centre in the eastern province (Agriculture, fishing, and trade services). Due to its main historical growth factors, the town experienced a quick urbanization process.

Due to ongoing development initiatives, Batticaloa City's infrastructure facilities will improve, but urban planners and other key development officials still need to plan these initiatives. The area is highly prone to arbitrarily constructed development, which impacts the sustainability of land use. Since 1979, rapid population growth has altered the authorities have not considered the completed pattern for sustainability. Because this area is the central urban hub accessible to all amenities in Sri Lanka's Eastern Province, migration from other parts of the district and the Eastern province increased to the Batticaloa city region because of the effects of the 30 years of the Civil War.

However, assessing whether the Batticaloa land use would accept this population expansion long-term necessitates a full grasp of the population's socio-economic characteristics and specific features of urban planning and the urban environment. Batticaloa's agricultural land and forest resources have suffered due to rapid population growth and low economic living conditions. According to Partheepan et al. (2016), demographic pressures contribute to greater competition for land, agricultural, and commercial areas. They claim that the demand for land to construct settlement infrastructure and other services increases as the population develops.

Fig.1 Study area - Batticaloa Town in Eastern Sri Lanka

3.2 Remote Sensing Data

In the present study, Landsat Thematic Mapper (LTM) and Operational Land Imager (OLI) data were used to obtain a 16-day repetition cycle with 30 m spatial resolution (Willis, 2015). To get cloud-free Landsat photographs for the research region shown in Tab.1, the US Geological Survey Earth Explorer, https://earthexplorer.usgs.gov/, was used (US Geological Survey, 2016). The acquisition quality of these photos was outstanding. The data were collected during the dry season between May and October best to distinguish the spectral signature of different land cover types.

Satellite type	Sensor type	Spatial resolution (metre)	Acquisition date	Source
Landsat 5	TM	30	17 September 1979	USGS: United States Geological Survey
Landsat 5	TM	30	4 August 2000	USGS: United States Geological Survey
Landsat 8	OLI	30	19 September 2021	USGS: United States Geological Survey

Tab.1 Details of Landsat data to analyse the LULCC in Batticaloa town by using Landsat data

3.3 Image Processing

These Landsat images were an L1T product topographically, geometrically, and systematically corrected. ArcGIS 10.3 software clipped the research region onto the Landsat image (ESRI, Redland, CA, USA) as a vector file. Before image classification, the preliminary image categorization was improved using ENVI 5.2 software to make radiometric and atmospheric corrections (Harris Geospatial, Broomfield, CA, USA)(Traore et al., 2018).

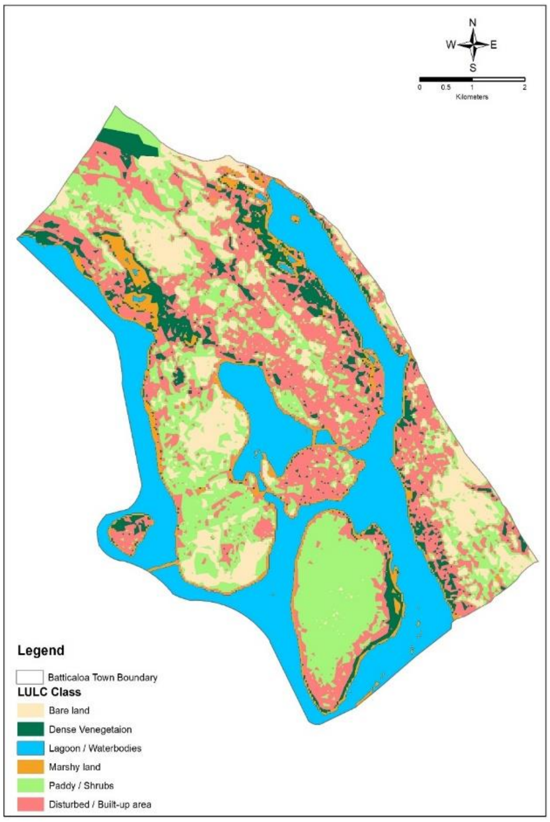
ID	LULC Classes	Description of Classes
1	Bare land	Non-occupied/open landmasses with little or marginal vegetation
2	Built-up area	All types of urban construction sites: residential, commercial, industrial, public buildings, roads network, and other similar facilities.
3	Dense Vegetation	Forest area, /fruit orchards, tree-covered areas, and temporary/permanent highland croplands.
4	Paddy & Shrubs	Paddy fields, grassland, shrubs, and other idle lands along the lagoon.
5	Marshy land	Mangrove land, Wetlands, Swamps
6	Water	Open water, lagoon, tanks, and ponds exist.

Tab.2 An overview of LULC classes

As shown in Tab.2, the support vector machine (SVM) classifier was used with the supervised classification scheme in ArcGIS 10 software (ESRI, Redland, CA, USA) to create four primary LULC classes.

The classes were adapted from (Anderson et al., 1976) with slight changes to fit the research topic. Comparing false-colour composites from Landsat 5TM and Landsat 8TM using spectral bands 5, 4, 3, 2, and 1 were used to construct each LULC class's training samples (see Fig.2). A cross-tabulation matrix for LULC changes was created. During the December 2021 study region field visit, Google Earth archival photos and ground control points were consulted when assembling the training samples.

(a)



(b)

(c)

Fig.2 Classified LULC maps for Batticaloa town in (a) 1979, (b) 2000 and (c) 2021

4. Results

4.1 Land Use/Land Cover Change Detection and Classification

Post-classification comparisons of bi-temporal maps were used to detect LULC changes. In this study, Landsat data from 1979, 2000, and 2021 to derive spatial and temporal patterns of LULC classes for the first period (1979-2000), the second period (2000-2021), and the overall period (1979-2021).

Batticaloa's urban LULC has altered dramatically during the last 42 years. The dense vegetation around water bodies (lagoons) was the most common terrain type in the study area. There were 27.79 per cent water bodies (lagoon), 24.82 per cent lush vegetation, 15.67 per cent bare land, and 15.60 per cent built-up area in 1979. The most notable changes are an increase in a built-up area and a depletion of greenery. From 1979 to 2021, the built-up area grew at an annual rate of 8.2 per cent. The built-up class grew slower at 3.65 per cent per year during the first era (1979–2000) than at approximately 4.55 per cent per year during the second era (2000–2021). The growing built-up area of Batticaloa Town is a sign of urbanisation. During the study period, vegetation land declined by 0.52 per cent yearly. The first era (1979–2000) saw a high annual rate of 0.82 per cent, followed by a meagre 0.24 per cent in the second decade (2000–2021).

Land use Land cover class	1979		2000		2021	
	User's accuracy (%)	Producer's accuracy (%)	User's accuracy (%)	Producer's accuracy (%)	User's accuracy (%)	Producer's accuracy (%)
Bare Land	100	86	91	96	88	91
Dense Vegetation	74	100	100	85	90	95
Paddy / Shrubs	72	98	98	86	96	93
Marshy land	70	100	100	89	95	92
Disturbed /Built-up Area	77	99	88	82	81	86
Lagoon/water bodies	100	100	100	98	100	100
Overall accuracy (%)		88.6		86.7		87.9
Kappa Coefficient		0.79		0.77		0.75

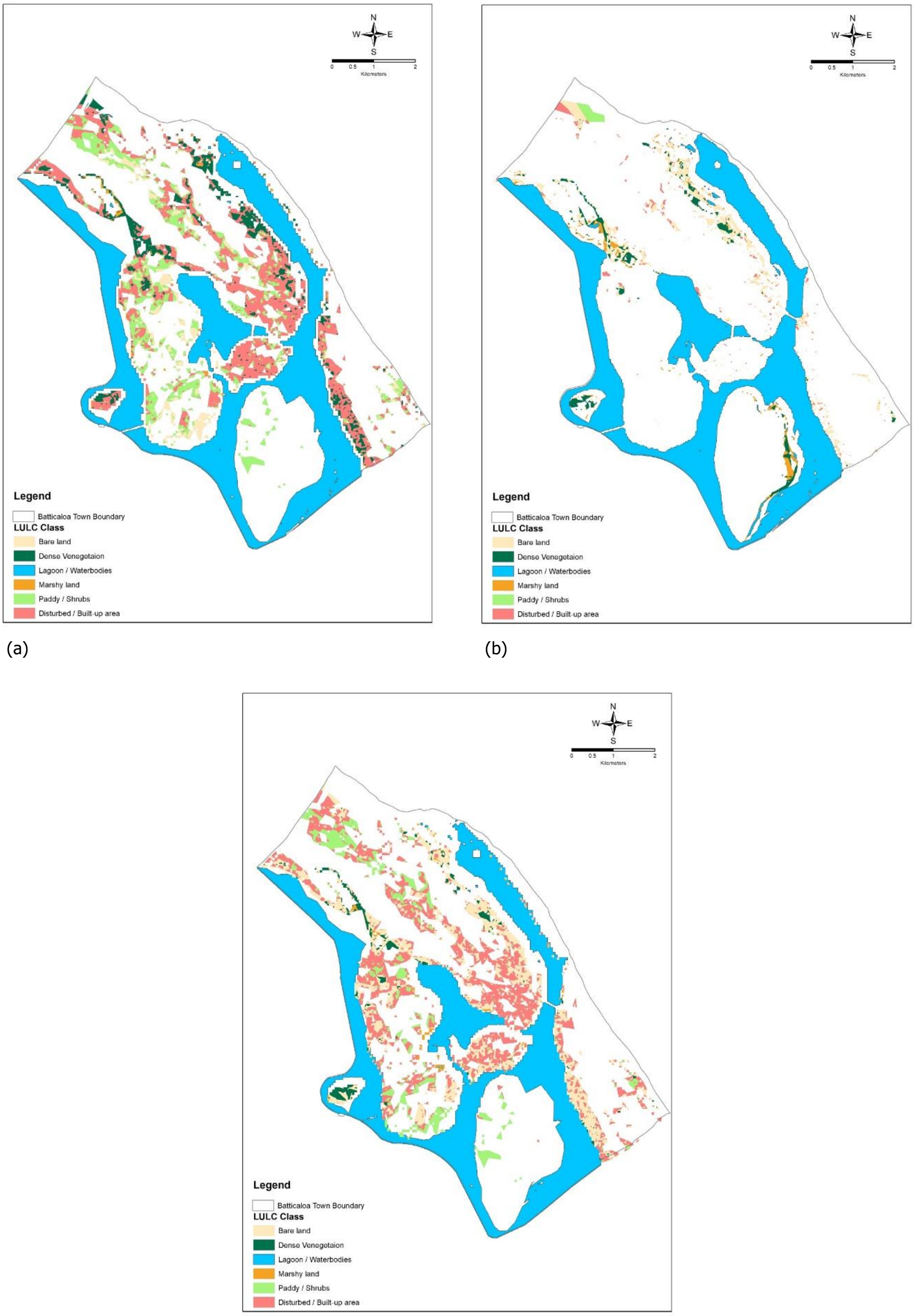
Tab.3 Accuracy assessment for 1979, 2000 and 2021 classified maps of Batticaloa Town

4.2 Land Use/Land Cover Change Detection and Classification

Tab.3 presents the accuracy assessment findings for LULC maps classified in 1979, 2000, and 2021. The total accuracy of the 1979, 2000, and 2021 images was 88.6, 86.7, and 87.9%, at least 85 per cent above the minimum standard set by the USGS. Therefore, after classification, the findings can be used as a data source for comparisons and further analysis. Strong agreement existed between the categorized map and the reference data, as indicated by the Kappa coefficients of 0.79, 0.77, and 0.75, respectively (Alo & Pontius, 2008).

4.3 Detection of post-classification changes

As a result of analyzing the classified maps for the first and second periods (1979-2000 and 2000-2021, respectively) and the total period (1979-2021), the transition matrix is presented in Tab.4. Tab.4a shows that approximately 59.21 per cent of the landscape changed from one type to another during the first period (1979–2000), but Tab.4b shows that about 47.27 per cent of the landscape changed during the second period (2000–2021), confirming that changes were faster in the early era.



(a) (b) (c)

Fig.3 Land use changes: conversion of Dense vegetation to other land classes (a) 1979, (b) 2000 and (c) 2021

Tab.5 provides the outcomes of computing gains, losses, total change, swap, and net change from the matrices as a benchmark for better understanding the transition budget. These calculations depict the interaction of the LULC classes in the terrain. According to Tab.5, shrubs/paddy land and vegetation classes have undergone a swapping type of alteration in this study.

For example, 5.76 and 16.39 per cent of the total modifications in the Paddy/shrub class were made in the first and second periods. Similarly, about 24.82 % and 12.94% of the overall change in vegetation class-switched places at the relevant periods. In addition, dense vegetation has been significantly changed around Batticaloa town and is geographically illustrated in Fig.3.

The simultaneous reforestation and deforestation actions in the environment may be to blame for the switching tendencies between paddyland/shrubs land and vegetation classes. For the first and second research intervals, the built-up type accounted for 15.67% and 18.63% of overall change in the class, respectively. The built-up area has been constantly expanded, as visualised in Fig.4.

The built-up type accounted for 15.67 per cent and 18.63 per cent of changes in the class, respectively, during the first decade.

Based on Tab.3, commission and omission errors are equal to the sum of the user and producer accuracy. Determining whether classification errors were responsible for the losses and swap proportions for the built-up class is impossible. Due to Landsat's 30 m spatial resolution and edge effects and the issues of spectrum confusion in the urban context, certain misclassifications may occur (Bhatta, 2009; Congalton & Green, 2008; Herold et al., 2005; Yang & Lo, 2010).

Moreover, the built-up areas occupied the highest proportion of the total area between 1979 and 2000, around 17%. Agriculture land gained around 21%, a smaller percentage than before 2000, and it lost considerably to the built-up areas. This change is partly attributed to more people moving into the study area from elsewhere in the district due to the civil war.

According to Fig.4, the urban expansion gradually increased from 1979 to 2021, changing approximately 1200 hectares. There was a small gain of about 17 per cent hectares from 1979 to 2000. After that, the urban expansion increased by more than 700 hectares between 2001 and 2006. In the decade between 2000 and 2021, there was a dramatic increase of around 700 hectares.

Similarly, 24.82 per cent and 12.94 per cent of vegetation class-switched sites changed during the relevant periods. Simultaneously environmental reforestation and deforestation efforts may explain this.

Switch between paddyland/shrubs land and vegetation classes. Additionally, shrubland/paddy land expansion is focused on vegetation and avoids densely populated areas, as illustrated in Fig.4. This procedure has reduced the vegetation cover in the research area, and agriculture has declined over time (Fig.4), possibly due to the tsunami effect in 2004, when seawater inundated agricultural grounds.

The standard of living has been dramatically improved through the construction of large houses and single-family homes during this time.

They had changed their lifestyle through modernization, and tiny houses and apartments needed to show the standard of living. There has been a noticeable impact on agricultural land and the rest categories. For example, parts of the town's suburban areas now lack agricultural land because of built-up areas (Fig.5). Similarly, between 2000-2021 the land use categories, such as agricultural and bare land, decreased to 14.19% and 12.58%, respectively.

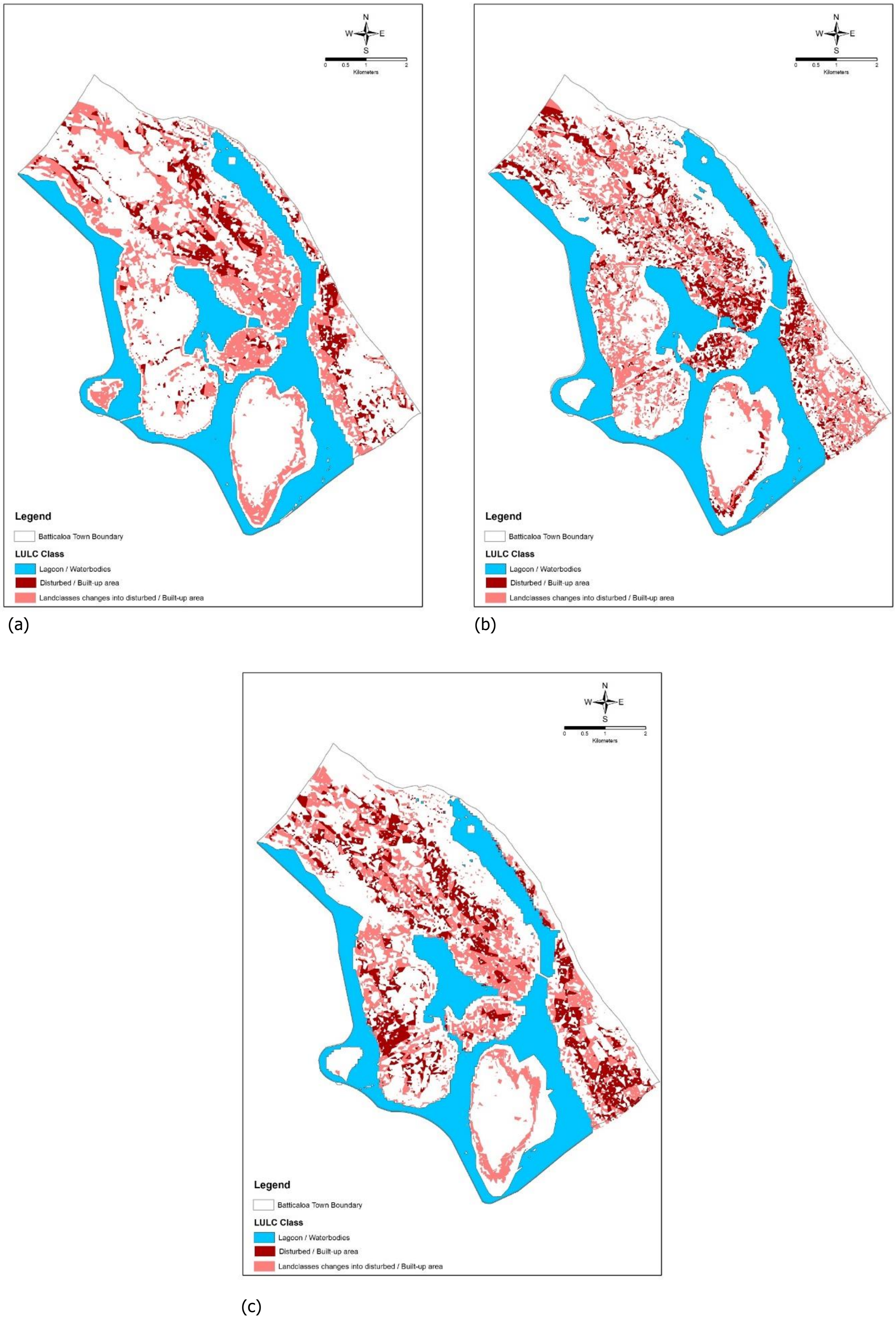


Fig.4 Land-use changes: land classes conversion to the built-up area / disturbed land (a) 1979, (b) 2000 and (c) 2021.

Fig.5 Land use changes: land classes conversion to shrubs/ paddy land (a) 1979, (b) 2000 and (c) 2021

(a) 1979-2000

		2000							
		Bare Land	Dense Vegetation	Water bodies	Marshy land	Shrubs/Paddy	Built-up Area	Total	Losses
1979	Bare Land	0.75	1.32	0.11	1.10	5.94	2.88	12.09	11.33
	Dense Vegetation	2.24	3.37	0.00	0.28	6.31	11.16	23.36	20.00
	Water bodies	0.00	0.01	24.92	0.61	0.00	0.05	25.59	0.67
	Marshy land	0.05	1.29	1.94	2.98	1.39	2.23	9.90	6.91
	Shrubs/Paddy	3.93	0.48	0.00	0.04	2.42	1.59	8.46	6.03
	Built-up Area	6.23	0.40	0.01	0.08	7.54	6.35	20.60	14.25
	Total	13.20	6.87	26.98	5.09	23.61	24.25	100.00	
	Gains	12.45	3.50	2.06	2.10	21.19	17.90		

(b) 2000 - 2021

		2021							
		Bare Land	Dense Vegetation	Water bodies	Marshy land	Shrubs/Paddy	Built-up Area	Total	Losses
2000	Bare Land	0.61	0.00	0.00	0.22	7.20	5.15	13.20	12.58
	Dense Vegetation	3.57	1.23	0.12	0.96	0.30	0.68	6.85	5.63
	Water bodies	0.00	0.00	26.64	0.32	0.00	0.00	26.97	0.33
	Marshy land	0.49	0.27	1.14	3.08	0.02	0.09	5.09	2.01
	Shrubs/Paddy	2.59	0.05	0.01	0.39	9.44	11.16	23.63	14.19
	Built-up Area	9.23	0.44	0.08	1.50	1.29	11.73	24.27	12.53
	Total	16.49	1.99	28.00	6.46	18.24	28.82	100.00	
	Gains	15.88	0.76	1.36	3.39	8.80	17.08		

(c) 1979 - 2021

		2021							
		Bare Land	Dense Vegetation	Water bodies	Marshy land	Shrubs/Paddy	Built-up Area	Total	Losses
1979	Bare Land	2.18	0.38	0.19	1.38	5.14	2.81	12.08	9.90
	Dense Vegetation	8.25	0.98	0.01	0.30	3.61	10.21	23.36	22.37
	Water bodies	0.02	0.00	25.20	0.33	0.01	0.00	25.58	0.37
	Marshy land	0.84	0.53	2.55	4.23	0.67	1.08	9.89	5.66
	Shrubs/Paddy	1.23	0.00	0.02	0.11	3.56	3.57	8.49	4.93
	Built-up Area	4.01	0.08	0.02	0.12	5.22	11.13	20.59	9.45
	Total	16.53	1.99	27.99	6.46	18.22	28.80	99.98	
	Gains	14.35	1.00	2.79	2.23	14.66	17.67		

Tab.4 The percentages represent the land use/land cover (LULC) transition matrix

(a) 1979-2000

LULC Class	Persistence	Gain	loss	Total Change	Swap	Net change
Bare Land	0.75	12.45	11.33	23.78	22.67	1.11
Dense Vegetation	3.37	3.50	20.00	23.49	7.00	-16.50
Water bodies	24.92	2.06	0.67	2.74	1.35	1.39
Marshy land	2.98	2.10	6.91	9.02	4.20	-4.81
Shrubs/Paddy	2.42	21.19	6.03	27.22	12.07	15.16
Built-up Area	6.35	17.90	14.25	32.16	28.51	3.65
Total	40.79	59.21	59.21	59.21	37.90	21.31

(b) 2000-2021

LULC Class	Persistence	Gain	loss	Total Change	Swap	Net change
Bare Land	0.61	15.88	12.58	28.46	25.16	3.3
Dense Vegetation	1.23	0.76	5.63	6.39	1.52	-4.87
Water bodies	26.64	1.36	0.33	1.69	0.66	1.03
Marshy land	3.08	3.39	2.01	5.4	4.02	1.38
Shrubs / Paddy	9.44	8.8	14.19	22.99	17.6	-5.39
Built-up Area	11.73	17.08	12.53	29.61	25.06	4.55
Total	52.73	47.27	47.27	47.27	37.01	10.26

(c) 1979-2021

LULC Class	Persistence	Gain	loss	Total Change	Swap	Net change
Bare Land	2.18	14.35	9.9	24.25	19.8	4.45
Dense Vegetation	0.98	1	22.37	23.37	2	-21.37
Water bodies	25.2	2.79	0.37	3.16	0.74	2.42
Marshy land	4.23	2.23	5.66	7.89	4.46	-3.43
Shrubs/Paddy	3.56	14.66	4.93	19.59	9.86	9.73
Built-up Area	11.13	17.67	9.47	27.14	18.94	8.2
Total	47.28	52.7	52.7	52.7	41.06	11.64

Tab.5 Land use and land cover changes (LULCC) summarised in percentage

5. Discussion

While many studies have demonstrated that remote sensing with geographic information technologies is an effective tool for detecting and mapping land use/cover change, few have conducted spatial and explanatory analyses. Anderson et al., 1976 suggest this is the most common method to detect changes., and it has been used successfully in several types of research, including (Briones & Sepúlveda-Varas, 2016; Hansen & Loveland, 2012; Jensen et al., 2007; Jiménez et al., 2018; Manandhar et al., 2009; Mawenda, 2020; Mwathunga & Donaldson, 2018; Ouedraogo et al., 2011; Shoyama & Braimoh, 2011; Yuan, 2007).

In Batticaloa town, substantial changes in all types of land use/cover occurred between 1979 and 2021, which can be attributed to the ethnic conflict. However, other factors contribute to these changes, including large-scale population displacements, military actions such as setting up high-security zones, the economic embargo, inadequate transportation and market facilities, and large-scale logging (Sarvananthan, 2009). The result of population displacement, high-security zones, and economic blockades has resulted in the loss of agricultural land within the city limits, primarily cultivated land. Despite the encroachment of built-up areas on previously dense forest areas, most changes occurred on shrubland. Over the past 42 years, Batticaloa town has seen increased anthropogenic-induced urban landscape changes. The expansion of the built-up area, which moved from 3.65% initially to over 4.55% in the later period, by an average annual change of 0.22%, supported this. The quick fall rates for vegetation and bare land are a source of environmental worry.

In another sense, due to its land consumption ratio, Batticaloa Town's urban expansion is becoming more comprehensive rather than compact. By integrating neighborhoods tightly and providing quick access to socio-economic services, this type of expansion harms the city's environmental sustainability and social interaction. Increased impervious surface area, reduced groundwater recharge, and increased solar radiation reflected in space worsen urban heat islands and floods (Sundarakumar et al., 2012). As a result, urban development is in jeopardy, and better management is required to ensure a more sustainable future.

Changing vegetation (flora, mangroves) contributes to a decrease in green space, negatively impacting ecosystem services such as water purification, flood mitigation, noise abatement, and urban cooling (Vargo et al., 2013). It also damages soil (Estoque & Murayama, 2013), resulting in areas that have been abandoned. Humans benefit from ecosystems that do not pertain to material possessions, such as spiritual enrichment, cognitive growth, introspection, recreation, aesthetic experiences, and their role in maintaining knowledge systems, social interactions, and aesthetic standards.

Environmental factors, demographics, and economic development influence Batticaloa town's land use/cover dynamic. As a result of Batticaloa's increased political and strategic importance as a development target after 2010, the city's infrastructure and urban areas have undergone substantial transformations, as has the region's land use pattern.

Finally, the shrinking of undeveloped regions places tremendous pressure on suitable properties for development. In unplanned settlements such as wetlands and lagoon buffer zones in Batticaloa town, climate change and climate variability have increased the frequency and intensity of floods in recent years (Konrad, 2003) (Partheepan et al., 2005a). These rigorous techniques suggest that the expansion of built-up regions is concentrated on bare ground, avoiding vegetated areas. Lands that cannot be developed, such as wetlands and buffer zones around the lagoon, can be found in most vegetated regions. Nevertheless, the post-war period following 2009 was politically stable, resulting in measurable growth in LULC changes, especially in built-up areas. In Batticaloa, 60% of the land area belongs to the private sector, so infrastructure investments drive the majority of change (Mapa et al., 2002).

Between 1979 and 2000, paddyland decreased due to deforestation and paddy land converted into built-up areas. The eastern and western parts of the Batticaloa district have different economic conditions. As a result of employment opportunities in the coastal belt, including Batticaloa town, there was a mass migration from west to east, and unproductive paddylands and shrubs were abandoned due to a labour shortage in agriculture in our study area. Rapid urban sprawl has been causing a significant loss of dense forests from 2000 to 2021, which has attracted the government's attention. In 2000 and onward, home garden acreage was barely over paddy lands, and it appears to be expanding with the rise in homesteads.

Similarly, cultivated lands in Batticaloa rose by 41.9 per cent from 2000 to 2005 due to the country's current peace process. Anthropogenic activities such as the exploitation of timber for fuel, the destruction of mangroves, and poor land management could explain this loss (Grogan et al., 2015; Lindström et al., 2012; Mahanama et al., n.d.; Partheepan et al., 2005b; Rathnayake et al., 2020; *Sri Lanka - Land Use Land Cover LULC (Change) Mapping - Datasets - Water data*, n.d.). Due to the transition and the terrible economic crisis, people began to overexploit the vegetative resources to sustain their livelihoods.

LULC changes during 2000-2021 concentrated in the Batticaloa town area. The aftermath of the civil war was attributable to open economic reforms, agricultural land expansion, population redistribution, and infrastructure upgrades, which had a significant impact after 2009 (Athukorala et al., 2017).

In this scenario, the underlying belief is that by relying heavily on technical analysis, which emphasizes objective data and scientific methods, a more effective and efficient approach to land use governance can be achieved. This aligns with the positivist philosophy that emphasizes the primacy of empirical evidence and the application of scientific principles in understanding and solving societal issues.

6. Conclusions

This study underscores the results obtained through the analysis of urban land use in Batticaloa from 1979 to 2021. The findings reveal a concerning trend of increasing built-up areas and bare land at the expense of vegetation and marshy areas. This transition from dense vegetation to barren land, and then to built-up areas, signifies inefficiencies in the city's approach to urban growth. These results provide important insights for policymakers and planners, emphasizing the need for prioritizing sustainable urban development in Batticaloa. Based on the study's findings, several recommendations emerge. The government should expedite the allocation of suitable land for development while curbing illegal expansion in high-risk areas. It is also crucial for planning bodies at the local authority, municipal, regional, and national levels to regularly assess physical plans and promptly provide serviced land. To mitigate the observed loss of vegetation cover, it is suggested to identify and conserve essential vegetation patches from human impact. Citizens can play a role by protecting vegetation on bare lands and other reserves in Batticaloa, allowing for natural regeneration.

Furthermore, the study highlights the strain on Batticaloa town's natural equilibrium over the four decades of population growth. The mapping of changes and disturbances in land use can serve as a valuable tool for landowners, non-governmental organizations (NGOs), and policymakers to protect environmentally fragile areas from further damage. This information can guide efforts to preserve and conserve the natural environment of Batticaloa. In addition to the specific findings on land use changes in Batticaloa, this study also proposes a time-series remote sensing analytical tool-chain for mapping land use and land cover change (LULCC) in highly dynamic tropical environments. This tool-chain aims to address the information gap caused by political instability and limited access to cloud-free images. By employing remote sensing techniques, policymakers and researchers can gain valuable insights into land use dynamics and make informed decisions for sustainable urban development. The research outcomes provide a significant contribution to the field of sustainable urbanization by highlighting the land use changes in Batticaloa and the need for sustainable development practices. The study emphasizes the importance of considering social equity, economic growth, and governance in comprehensive evaluations of urban sustainability. By integrating these dimensions and addressing the identified challenges, policymakers and planners can work towards creating a more sustainable and resilient future for Batticaloa and similar urban areas.

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Image Sources

All images are by the Authors.

Fig.1: Study area—Batticaloa Town in Eastern Sri Lanka;

Fig.2: Classified LULC maps for Batticaloa town in (a) 1979, (b) 2000 and (c) 2021;

Fig.3: Land use changes: conversion of Dense vegetation to other land classes (a) 1979, (b) 2000 and (c) 2021;

Fig.4: Land-use changes: land classes conversion to the built-up area / disturbed land (a) 1979, (b) 2000 and (c) 2021;

Fig.5: Land use changes: land classes conversion to shrubs/ paddy land (a) 1979, (b) 2000 and (c) 2021.

Author's profile

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Kulasegaram Partheepan, a PhD student at the Faculty of Technology, South Eastern University of Sri Lanka, is an experienced development professional with over 16 years of involvement with the United Nations. He has dedicated his career to supporting crisis recovery efforts in the North and East provinces of Sri Lanka. Partheepan is actively engaged in research within the fields of Geoinformatics, Climate Change, and Environmental Science. He holds an MSc in Geoinformatics from the Postgraduate Institute of Agriculture at the University of Peradeniya. Furthermore, he completed his bachelor's degree at the Eastern University of Sri Lanka.

Muneeb M. Musthafa

Dr. Muneeb M. Musthafa is a senior lecturer and head of Biosystems Technology, Faculty of Technology, South Eastern University of Sri Lanka, Sri Lanka. He has been an active researcher in the field of ecology, biodiversity, conservation, environmental science and animal science. He has completed PhD from the University of Malaya, Malaysia under the International Graduate Research Scholarship, where he carried out his research on beetle diversity in a montane ecosystem of Malaysia. He has completed his bachelor's degree from the University of Peradeniya, Sri Lanka and his MSc in Animal Science from King Saud University, Saudi Arabia under scholarship, where he has worked on a number of projects related to genetic diversity of goat and sheep of Saudi Arabia. Then he extended his research expertise at China (Chinese Academy of Agricultural Sciences, Beijing) on fecundity gene and Ege University, Turkey. So far, he has produced more than 50 peer-reviewed, indexed journal research articles, while participating in a number of international conferences. He is a member of a number of international societies and recently became the chief editor of a new journal called Sri Lankan Journal Technology. He has contributed immensely to establishing postgraduate research degree programs at the Faculty of Technology, South Eastern University of Sri Lanka, Sri Lanka. Recently he is working on microplastic pollution in marine ecosystems in collaboration with the Centre for Environment, Fisheries, and Aquaculture Science (CEFAS), UK.

Thangamani Bhavan

Thangamani Bhavan is a Professor in Economics, attached to the Department of Economics, Faculty of Commerce and Management, Eastern University, Sri Lanka. He received his PhD in Western Economics at the School of Economics, Huazhong University of Science and Technology, and his MSc in Agricultural Economics at the Postgraduate Institute of Agriculture, University of Peradeniya. His teaching and research interests are in the area of international financial flows, Trade, and Environmental Resource Management.