Geospatial Analysis of Land Use/ Land Cover Changes in the Northern Province, Sri Lanka

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Abstract

Knowledge of the geographical distribution of land use/ cover and the trends and patterns of their change is required for spatial planning and management of a country's land resources. Satellite remote sensing and Geographic Information Systems are becoming more significant in the study of changes in land use/ cover. The objectives of this study are to identify the spatial and temporal change in land use/cover and to understand the dynamics of trends and patterns of land use/ cover in the Northern Province of Sri Lanka between 1990 and 2020 using satellite remote sensing and spatial analysis techniques. Maximum likelihood supervised image classification is used to create the signature class of significant land use/ cover category. After ensuring a satisfactory accuracy value for each classified image, a detailed post-classification change detection analysis was executed. The dynamic degree of land use/ cover change and vulnerability of land use/ cover change were also analyzed to evaluate changes quantitatively. There were major changes in land use/ cover, particularly after ending the civil war, due to increasing resettlements, development initiations, and agricultural expansion in the Northern Province. Indiscriminate deforestation has had a significant impact on the habitat of wildlife, and due to that, the frequency of human-wildlife conflict has increased. Therefore, accurate land cover change detection helps to monitor deforestation, urbanization, and agricultural expansion, allowing us to take timely actions for conservation practices and decision-making for sustainable development in the Northern Province.

Keywords: Geographic Information Systems, Land Use/ Land Cover Change, Remote Sensing, Satellite Images

1. Introduction

The land is the basis and essential natural resource for peoples' survival, livelihood, and development. Land use and land cover refer to two essential features of land: human-induced characteristics and physical or biotic properties of the environment [1][2]and [3]. *Land cover* is the observed physical cover of the earth's surface, such as forests, mountains, and built-up areas. In contrast, land use refers to human use of land such as homesteads, agriculture, and residential areas. However, in many instances, land use and land cover are used interchangeably when remote sensing data from the principal data source [4]. Land-use change is a vital cause for changing people's livelihood and environment [5]. Human-caused land use/ cover change has been identified as the key driving element for eco-environmental evolution and climatic change, and it has substantially influenced human society's long-term growth [6]. Population expansion, socio-economic development, and the accelerating process of urbanization and industrialization are the major contributors to land use changes [7].

Over the last few decades, there has been a substantial shift in global land use [8]. Historically, population increase has been the primary driving force behind most land use/ cover changes [9]. Increased food consumption due to population increase has imposed significant pressure on land resources. Several studies pointed out that population growth contributes to land use/ cover changes, especially forest fragmentation, deforestation, and forest degradation [10][11] and [12].

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It can be the most significant factor for future global environmental, social, and economic issues. In Sri Lanka, the growing population and intensive agricultural activities generally altered land-use patterns throughout the nineteenth and twentieth centuries, putting more strain on the land. The quantity of land set aside for conservation was constantly decreasing.

Satellite remote sensing and geographic information systems (GIS) are widely employed to detect and assess land-use changes. Satellite remote sensing collects multispectral and multitemporal data to assess the type, amount, and location of land use/ cover change. GIS provides a versatile platform for presenting, storing, analyzing, and evaluating digital data required for change detection. Information on land use/ cover and best-used options are critical for selecting, planning, and implementing land use plans to satisfy the growing demand for fundamental human requirements and well-being [10][13] and [14].

The Northern Province had been the focal point of the armed conflict between Sri Lanka's government and the Liberation Tigers of Tamil Eelam (LTTE), a separatist organization fighting for an independent Tamil homeland - Tamil Eelam - for more than three decades [15]. Consequently, unlike other parts of Sri Lanka, the province was severely affected, with prominent Tamil and Muslim populations migrating from this region. After ending three decades of inland armed conflict, Sri Lanka put various development plans in place, from the local to the national level, to meet the demands of an expanding population. Development projects and resettlement activities accelerated the changes in land use/cover. As a result, Northern Province underwent various ecological, social, and economic consequences [16]. Population increases through resettlement, new settlement activities, and expansion of agriculture have led to the conversion of protected areas into productive and urban uses in the Northern Province.

The available information on land use, land use/ cover change, topographical maps, statistical figures, and publications is inadequate and not current in the Northern Province of Sri Lanka. The most recent land use information is associated with the topographic map compiled in 2010 by the Survey Department of Sri Lanka. A study published in 2008 covered the topic of land use changes in the Jaffna Peninsula for the period from 1984 to 2004 [15]. Also, [17] examined the vulnerability of land use/ cover change in the Mullaitivu district only from 1994 to 2020. The need for more quantitative and accurate information on existing land use/ cover and associated temporal and spatial changes has hampered spatial planning and development activities. As such, the study attempts to map, quantify, and analyze the land use/ cover spatial-temporal pattern and process of land use/cover changes in Northern Province between 1990 and 2020 using satellite remote sensing and spatial analysis techniques.

2. Materials and Methods

2.1 Study Area

Sri Lanka is an island situated in the Indian Ocean. The study area, Northern Province, is located north of Sri Lanka. It is connected with the Indian mainland by the mythical Adam’s Bridge. It is bounded by northern latitudes between 8º 31′ 2″N and 9º 49′ 37″N, and eastern longitudes between 79º 37’ 5″E to 80º 58′ 45″E, as shown in Figure 1.

The Northern Province is one of Sri Lanka's nine provinces and the country's first administrative unit. The province covers an area of 8,890.07 Km^2 comprising approximately 13.54% of the island's total land area. Gulf of Mannar binds it on its western, Palk Strait in the north, the Bay of Bengal on the east side and Districts of Puttalam, Anuradhapura and Trincomalee in the south. Northern Province consisted of five administrative districts: Jaffna, Kilinochchi, Mannar, Mullaitivu and Vavuniya. The province's capital is Jaffna. There are 34 Divisional Secretariats, which are made up of 921 Grama Niladhary Divisions, and 34 Local Authorities, which are made up of one Municipal Council, five Urban Councils, and 28 Pradhasiya sabas. The population density of the province was 949.01 persons per Km^2, while the island's population density was 326.37 in 2019 [18].

2.2 Data Sets

This study mainly used secondary data sources, including six series of multi-temporal and multi-spectral Landsat images from 1990 to 2020 with different sensors, including ETM+ in 1996, TM in 1990, 2002 and 2008, OLI in 2014 and 2020. Satellite paths and rows (Land sat path 142 row 53, path 142 rows 54 and path 141 row 54) with a spatial resolution of 30X30m were downloaded from United States Geological Survey earth explorer (https://earthexplorer.usgs.gov/) individually for the above six periods and required bands. These images were rectified, geo-referenced, mosaic, and merged individually for every band. In TM, ETM+ images, bands 1, 2,3,4 and bands 2,3,4,5 in OLI images were mosaicked for individual bands with the ArcGIS 10.3.

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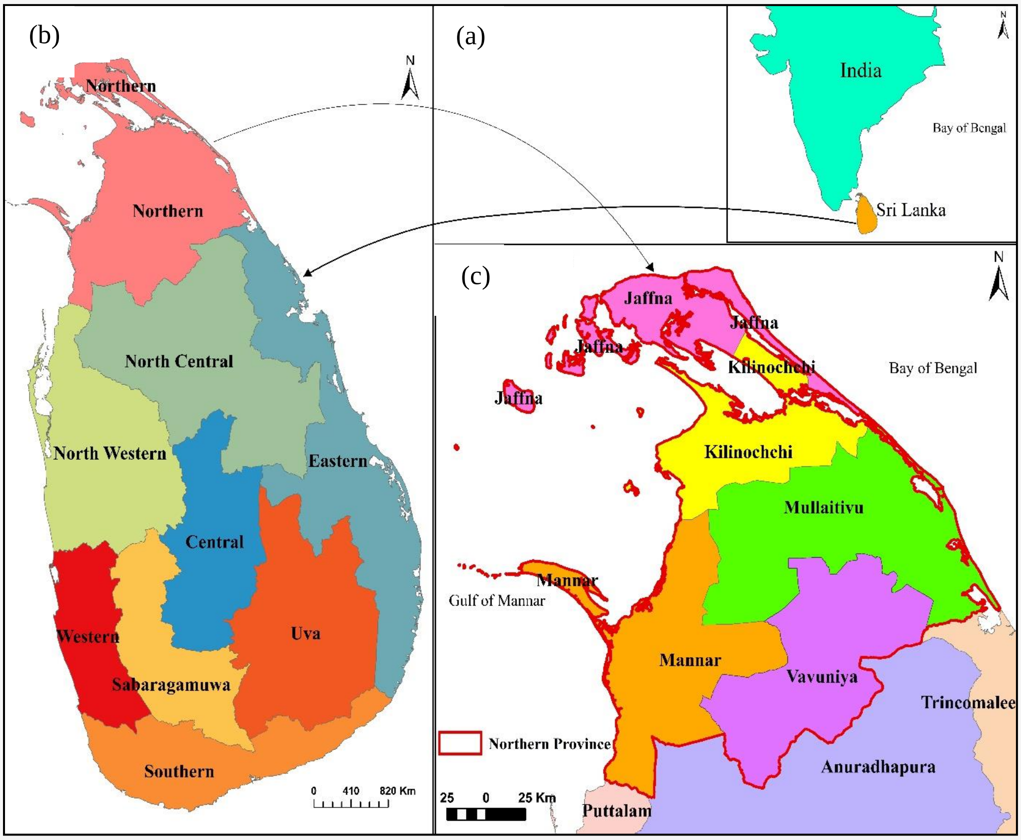

Figure 1: Location of the study area: (a) Location of Sri Lanka, (b) Provinces of Sri Lanka, (c) Northern province with five districts

All images were obtained for the same season for the periods 11-10-1990, 09-10-2002 and 02-10-2008 (Landsat TM), 02-10-1996 (Landsat ETM+), and 20-10-2014, 04-10-2020 (Landsat OLI) to minimize the illumination effect for change detection analysis. Field visits were conducted to collect ground truth samples for assessing the accuracy of classified land use/ cover in images, validate the results of land use/ cover interpretation and describe the characteristics of each land use/ cover. ArcGIS 10.3 was used to create the geographical database and statistically examine land use/ cover change.

2.3 Methods

Several geospatial analyses, such as Image Classification and Accuracy Assessment**,** Land Use/ Cover Change Analysis**,** dynamic degree analysis, and vulnerability analysis, were used for land use/ cover mapping and change analysis. These techniques have been elaborated on in detail in this section.

2.3.1 Image classification and accuracy assessment

Landsat images for the years 1990, 1996, 2002, 2008, 2014, and 2020 were used for image classification. The Supervised image classification method with the Maximum Likelihood Algorithm was applied to classify images into land use/ cover information for the six periods. Six land use/ cover classes were delineated as dense forest, scrub, agriculture, homestead, barren land, and water bodies/wetlands. The Kappa Coefficient was used to calculate the accuracy assessment of the land use/ cover maps. Accordingly, the kappa coefficients are 0.86, 0.85, 0.757, 0.761, 84.24, and 0.852 for 1990, 1996, 2002, 2008, 2014, and 2020, respectively.

Classified land use/ cover maps and statistics were used to derive the quantitative and qualitative information of land use/ cover changes. Change detection analysis was carried out using ArcGIS. Six pairs of classified land use/ cover maps, 1990 -1996, 1996 – 2002, 2002 – 2008, 2008 – 2014, 2014 - 2020 and 1990 - 2020 were compared, analyzed and statistics were derived.

2.3.2 Land Use/ Cover change analysis

Classified land use/ cover maps and statistics were used to derive the quantitative and qualitative information on land use/ cover changes. The post-classification comparison change detection method was employed to quantify the land use/ cover changes in this research. This method compares two independently produced classified land use/ cover maps on two dates. It is a widely used procedure for land use/ cover change detection analysis [19] and [20]. It shows how sensitive it is to change a particular land use into another land use. It is identified by a Transition Matrix (TM). The transition matrix is a fundamental tool for analyzing quantitative and qualitative data about the land use/ cover within the two prescribed years [21]. A change detection transition matrix with cross-tabulated land use classes was used to identify land use/ cover class transformations. The Transition Matrix displays whether pixels on the two dates belong to the same land-use class or have moved to a different one. Accordingly, the transition matrix describes how much land use/ cover percentage in the initial period changes into other land use/ cover in a subsequent period. The transition matrix follows a format such that the rows display the categories of an initial period, and the columns display the categories of a subsequent period. The main diagonal elements designate the proportion of persistent land use/ cover classes that show no changes. In this study, six pairs of classified land use/ cover maps, 1990 -1996, 1996 – 2002, 2002 – 2008, 2008 – 2014, 2014 - 2020, and 1990 - 2020, were compared and analyzed for land use/ cover changes. Change detection analysis was carried out using ArcGIS software. GIS analysis was used to map the changes in land use in detail.

2.3.3 Analysis of dynamic changes in single and synthesized Land Use/ cover

The land use/ cover change rate can be expressed by the land use dynamic degree model, demonstrating the difference in land use/ cover change through time and forecasting the trend of land use/ cover change in the future. A single land-use dynamic degree can indicate the annual quantity change of a specific land-use type in a region over time. Synthesized land use/ cover change can be described by the comprehensive regional land use/ cover dynamic change [21][22][23] and [24]. The rates of single land use/ cover change and synthesized land use/ cover change were derived from Equations 1 and 2.

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\%$$

Equation 1

Where:

K = the land use type degree of a specific kind of land in the research period,

U_a and U_b = the quantities of a specific kind of land use type at the initial and subsequent of the research period.

T = the research period. K signifies the yearly change rate of a certain land use type in the study area where the unit of T is year.

$$LC = \left[\frac{\sum_{i=1}^{n} \Delta LU_{i-j}}{\sum_{i=1}^{n} LU_i} \right] \times \frac{1}{2T} \times 100\%$$

Equation 2

Where:

LU_i = the area of the ith kind land use type at initial of research period

ΔLU_{ij} = represents the area absolute value of the i^{th} kind land type changed to non-i^{th}kind land type

T = the study period

LC = The annual synthetical change rate of land use type in the study area

2.3.4 Vulnerability analysis

Vulnerability of land use/ cover means sensitivity to changing a particular land use/ cover into another land use/ cover. The vulnerability of land use/ cover was identified using a transition matrix. In a vulnerability table, the loss column shows the amount of land use/ cover that experienced a net loss of a particular class between two periods, whereas the gain rows reveal the amount of land use/ cover that experienced a gross gain of other classes between the two periods. The gain-to-persistence (Gp), loss-to-persistence (Lp) and net-to-persistence (Np) were derived from equations 3-5. These statistics are used to assess each land use/ cover class's vulnerability to the transition based on the gain and loss statistics.

$$Gp = \frac{g}{p}$$

Equation 3

Where:

Gp = Gain-to-persistence

g = gain

p = persistence

$$Lp = \frac{l}{p}$$

Equation 4

Where:

Lp = Loss-to-persistence

l = loss

p = persistence

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$$Np = Gp - Lp$$

Equation 5

Where:

Np = Net-to-persistence
Gp = Gain-to-persistence
Lp = Loss-to-persistence

Gain, persistence (portions of a given category that stayed unaltered), and loss are represented by the letters g, p, and l. Gp and Lp values larger than one indicates that a given land-cover class has a higher chance of changing to another than remaining in its current state. If Np were negative, the land-cover class would have a more significant chance of losing area to other land-cover classes than gaining it [25] and [26].

3. Results and Discussion

3.1 Temporal and Spatial Land Use/ Cover Pattern

Land use/ cover maps for the years of 1990, 1996, 2002, 2008, 2014 and 2020 are shown in Figure 2. As depicted in the categorised land use/ cover maps, six land use/ cover types and associated dynamics were identified: Dense Forest, Agriculture, Homestead, Scrub, Barren land and Waterbodies. According to the classified land use/ cover maps of Northern Province, the centre part, tends to be more forested and has undergone more agricultural land, homestead, and scrub. Conversely, Northern Province's upward (Jaffna district and part of Kilinochchi district) and other town areas had more built-up areas and homesteads in the study period. Mullaitivu district had the largest forested area in 1990, rapidly decreasing during the 30-year study period. The results indicate that, in 1990, from the total area of 8,890 Km^2, dense forest for 4,241 Km^2(47.71%), homesteads accounted for 1,448 Km^2(16.29%), agriculture for 1,501 Km^2 (16.88%) and scrub for 835 Km^2(9.39%). The other land use/ cover, the barren land and water bodies together, accounted for 865 Km^2(9.73%). Analysis of the 2020 image also showed that dense forest accounted for 2,102 Km^2 (23.64%), homesteads for 2,633 Km^2(29.62%), agriculture for 2,315 Km^2(26.04%), and scrub for 1,226 Km^2(13.79%).

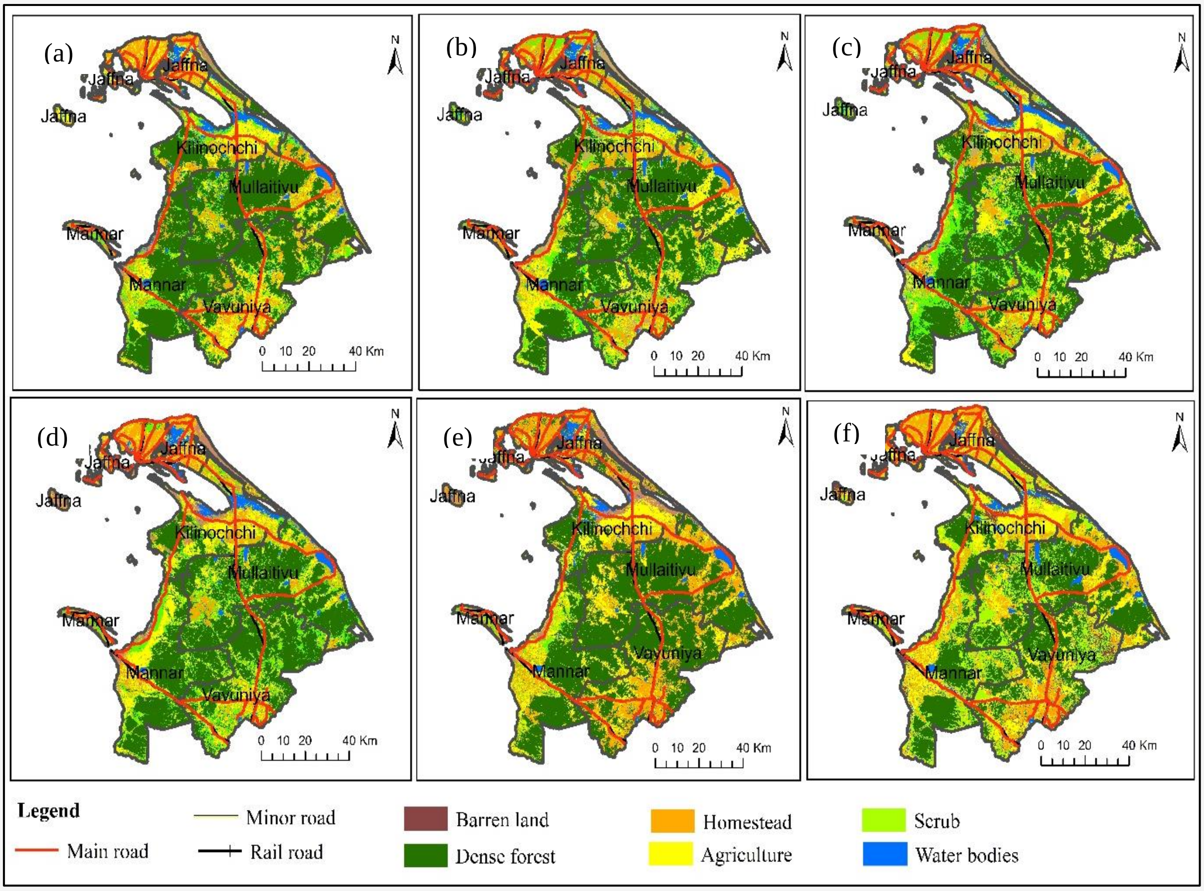

Figure 2: Land Use/ Cover pattern (a)1990, (b)1996, (c)2002, (d)2008, (e)2014, and (f) 2020

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Table 1: Area of Land use/ cover in Northern Province 1990-2020

LULC Type	1990		1996		2002		2008		2014		2020	
	Area (Km^2)	Area (%)	Area (Km^2)	Area (%)	Area (Km^2)	Area (%)	Area (Km^2)	Area (%)	Area (Km^2)	Area (%)	Area (Km^2)	Area (%)
Agriculture	1,501	16.88	1,731	19.47	1,832	20.61	1,682	18.92	1,934	21.75	2,315	26.04
Barren land	320	3.6	317	3.57	321	3.61	256	2.88	231	2.6	252	2.83
Dense forest	4,241	47.71	4,012	45.13	3,879	43.63	3,794	42.68	3,259	36.66	2,102	23.64
Homestead	1,448	16.29	1,667	18.75	1,680	18.9	1,937	21.79	2,341	26.33	2,633	29.62
Scrub	835	9.39	660	7.42	745	8.38	794	8.93	742	8.35	1,226	13.79
Water bodies	545	6.13	503	5.66	433	4.87	427	4.8	383	4.31	362	4.17
Grand Total	8,890	100	8,890	100	8,890	100	8,890	100	8,890	100	8,890	100

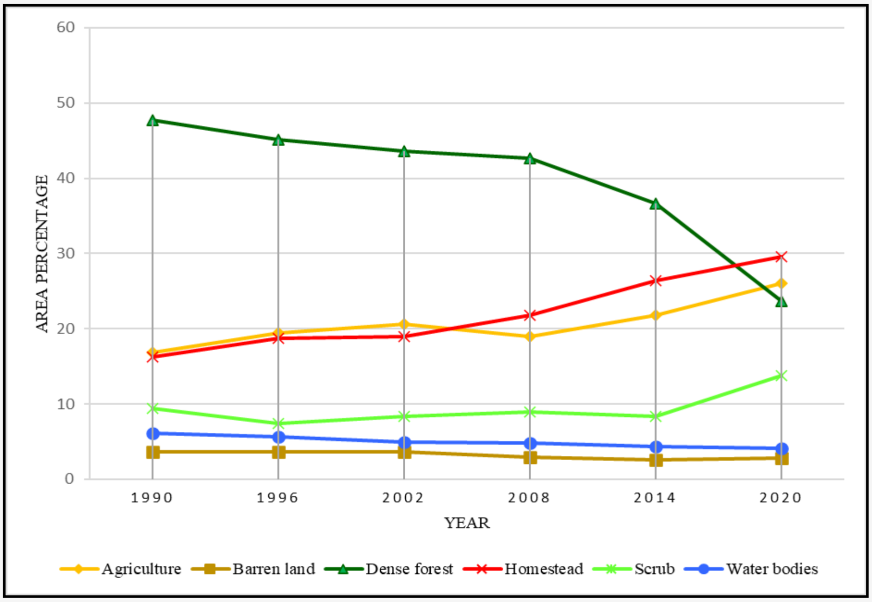

Figure 3: Land Use/ Cover Trend in Northern Province 1990 – 2020

Changes in the land use/ cover for 1990, 1996, 2002, 2008, 2014 and 2020 were analysed. The land use/ cover pattern of the Northern Province has been changing dynamically since 1983 because ethnic conflict escalated into civil war in 1983. However, land use/ cover has changed dramatically from 1990 to 2020 in the Northern Province. The distribution of land across the six-land use/ cover classes in 1990, 1996, 2002, 2008, 2014 and 2020 is summarized in Table 1.

The trends in land use/ cover changes from 1990 to 2020 are shown in Figure 3. It shows every six-year fluctuation of land use/ cover in the study area during the 30-year study period (1990 – 2020). From this figure, it can be seen that all land use/ cover categories generally fluctuate. The most general trend observed is decreased dense forest, barren land, and water bodies and increased agricultural land, homestead, and scrub. Homestead constantly increased in the last 30 years (1990 – 2020) and particularly, increased significantly between 2008 and 2020. Agriculture also increased significantly after 2008. On the other hand, the dense forest decreased significantly from 2008 to 2020. There has been a significant land use/ cover change in the individual category in the Northern Province, where the agricultural land covered 16.88% in 1990, increased to 19.47% in 1996, 20.61% in 2002 and decreased to18.91%, rapidly increased to 21.75% in 2014, 26.04% in 2020. The homestead covered 16.29% in 1990, which slightly increased to 18.7, 18.9 and 21.79% in 1996,2002 and 2008. After the end of the conflict in 2009, the homestead rapidly increased to 26.33% and 29.62% in 2014 and 2020. The area occupied by dense forest decreased from 47.41% in 1990, 45.13% in 1996, 43.63% in 2002, 42.68% in 2008, 36.66% in 2014 to 23.64% in 2020. This could be attributed to the increase in population, increasing the demand for agricultural and built-up land in the Northern Province after the armed conflict.

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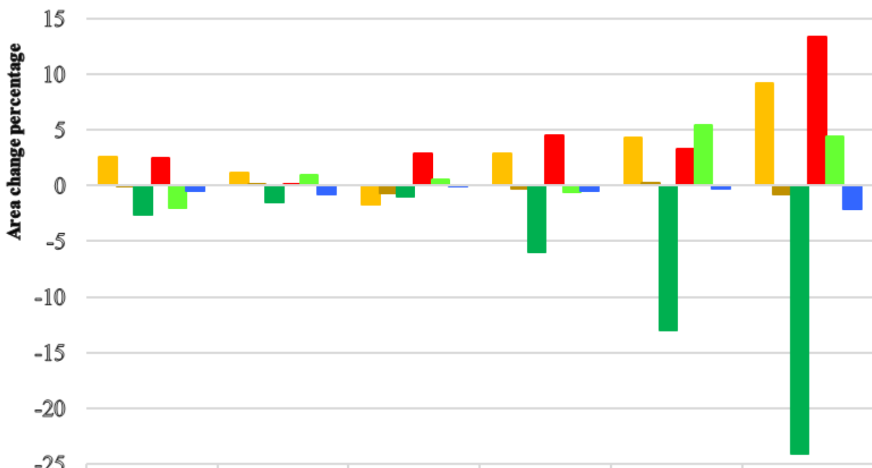


	1990-1996	1996-2002	2002-2008	2008-2014	2014-2020	1990-2020
Agriculture	2.59	1.14	-1.69	2.83	4.29	9.16
Barren land	-0.03	0.04	-0.73	-0.28	0.23	-0.77
Dense forest	-2.58	-1.5	-0.95	-6.02	-13.02	-24.07
Homestead	2.46	0.15	2.89	4.54	3.29	13.33
Scrub	-1.97	0.96	0.55	-0.58	5.44	4.4
Water bodies	-0.47	-0.79	-0.07	-0.49	-0.24	-2.06

Figure 4: The area changes of land use/ cover between 1990 and 2020 (%)

3.2 Land Use/ Cover Changes

The critical changes in several land use/ cover categories during the previous three decades are shown change map, a transition matrix, a dynamic degree of single land use/ cover change and a dynamic degree of synthesised land use/ cover change. Figure 4 shows the area change of land use/ cover between 1990 and 2020. The results indicated that between 1990 and 1996 (about six years), average agricultural land increased by 2.59%, while the homestead continued to increase by 2.46%. The area covered by barren land and water bodies dropped by 0.03% and 0.47%, respectively. After completing three decades of armed conflict (2009), the Postwar development phase was started. During this period (2009 – 2020), dense forests rapidly decreased for agricultural development and homestead activities. The results indicated that between 2008 and 2014 (about six years), average agricultural land increased by 2.83%while the homestead continued to increase by 4.54%. The dense forest and scrub area decreased by 6.02% and 0.58%.

Between 2014 and 2020 (about six years), the area covered by agricultural land, homestead and scrub increased by 4.29%, 3.29% and 5.44%, while dense forest rapidly decreased by 13.02%, and water bodies slightly decreased by 0.24%. This land use/ cover change was harvesting trees for timber and converting natural forests to agricultural land, homestead and resettlement areas.

3.3 Land Use/ Cover Change Matrix

Spatial and temporal land use/ cover are meaningless as they only consider the addition or deduction of areas of land use/ cover. It is possible to know the changes in the spatial pattern of specific land use/ cover and the quantitative value of changes in the land use/ cover for 1990 and 2020 by spatial GIS operation and transition matrix (TM) methods, respectively. The spatial GIS operation, overlay analysis, makes it possible to know the spatial pattern of changes ('from to' change) of a particular land use/ cover during the research period. It is shown in Figure 5. Accordingly, the dense forest has been largely converted into residential, agricultural and scrublands due to resettlement activities and agricultural and other development activities. During 1990 -2020, most land use/ cover changed from agricultural land to homestead, dense forest to scrub and dense forest to homestead. The transition matrix assesses the continuous changes which and how many changes in land use/ cover occurred during the last 30-year period (Table 2).

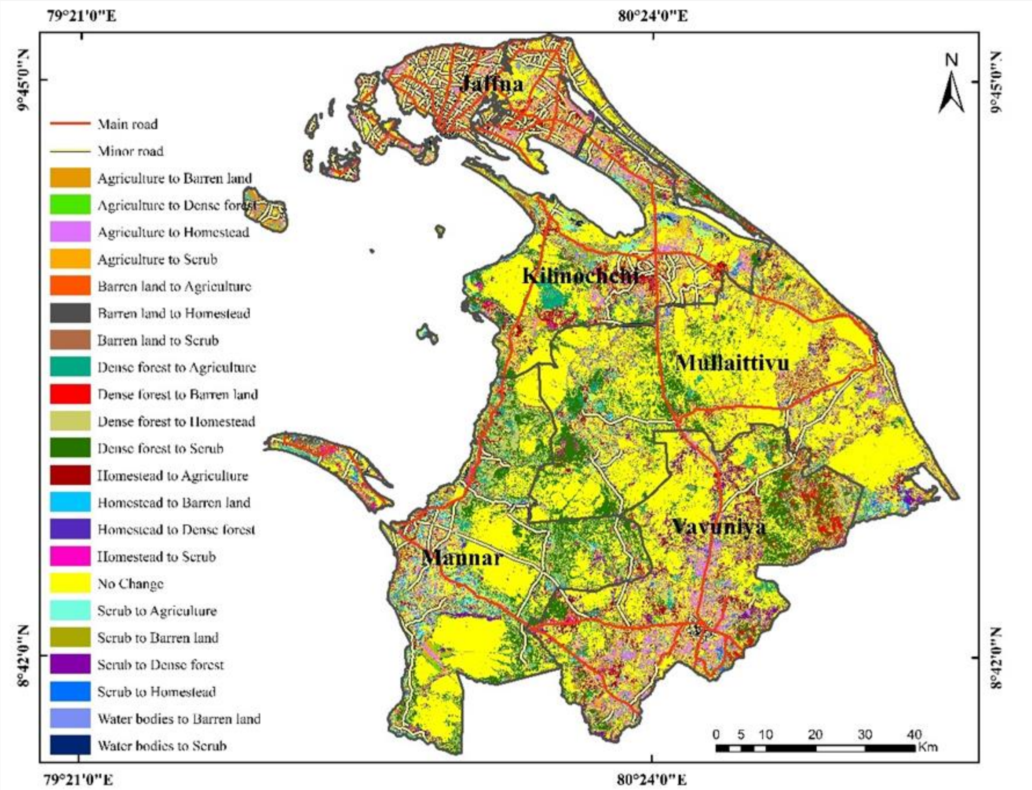
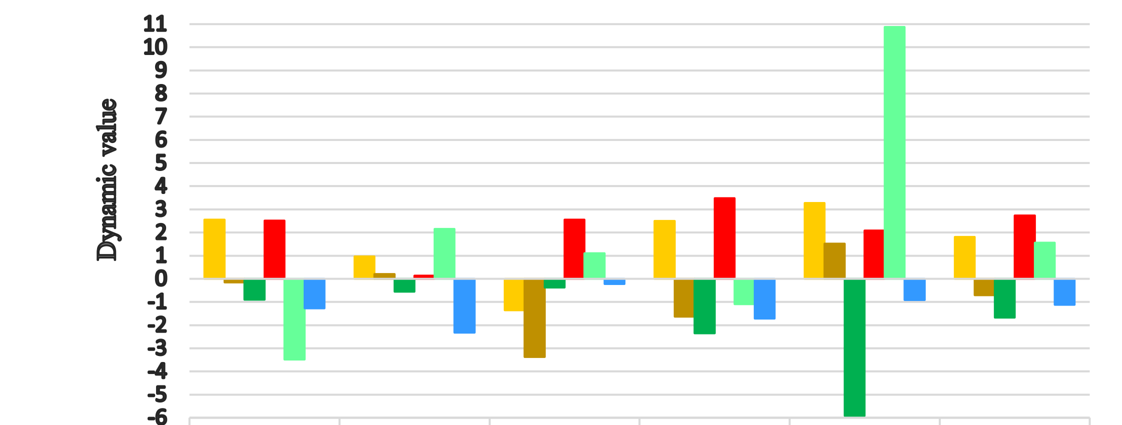


Figure 5: Land Use/ Cover Change in Northern Province 1990 – 2020

Table 2: Land Use/ Cover change matrix in Northern Province 1990 – 2020

Land Use/ Cover Types		2020 Area (Km^2)						Grand Total 1990
		Agriculture	Barren land	Dense forest	Homestead	Scrub	Water bodies	
1990 Area (Km^2)	Agriculture	**1,043**	29	44	320	60	5	1,501
	Barren land	138	**33**	14	56	72	7	320
	Dense forest	586	79	**1,930**	749	887	10	4,241
	Homestead	319	13	18	**1,069**	19	10	1,448
	Scrub	187	57	57	396	**121**	17	835
	Water bodies	42	41	39	43	67	**313**	545
Grand Total 2020		2,315	252	2,102	2,633	1226	362	8,890

Accordingly, the values in rows in Table 2 denote the area of land use/ cover in 1990, and the values in the column stand for the area of land use/ cover in 2020. The values in the main diagonal area of the transition matrix designate unchanged land use/ cover classes from 1990 to 2020. It can be made out that the dense forest has been mainly changed into the scrub, homestead, and agriculture, and the scrub was mainly changed into barren land, agriculture, and homestead, etc. Dense forests accounted for $4024Km^2$ area in 1990 and $2089Km^2$ in 2020, respectively. The extent of barren land, on the other hand, declined somewhat from 2.33% to 1.89%. Between 1990 and 2020, scrubland, agricultural, and homestead increased from $980Km^2$, $1470Km^2$,$1639Km^2$ to $1637Km^2$, $1728Km^2$, and $1928Km^2$, respectively. The loss of dense forest is the highest, representing $1155Km^2$ of the total land cover.



	1990-1996	1996-2002	2002-2008	2008-2014	2014-2020	1990-2020
Agriculture	2.55	0.97	-1.36	2.5	3.28	1.81
Barren land	-0.16	0.21	-3.37	-1.63	1.52	-0.71
Dense forest	-0.9	-0.55	-0.37	-2.35	-5.92	-1.68
Homestead	2.52	0.13	2.55	3.48	2.08	2.73
Scrub	-3.49	2.15	1.1	-1.09	10.87	1.56
Water bodies	-1.28	-2.32	-0.23	-1.72	-0.91	-1.12

Figure 6: Dynamic change of single land-use type (%) 1990 – 2020

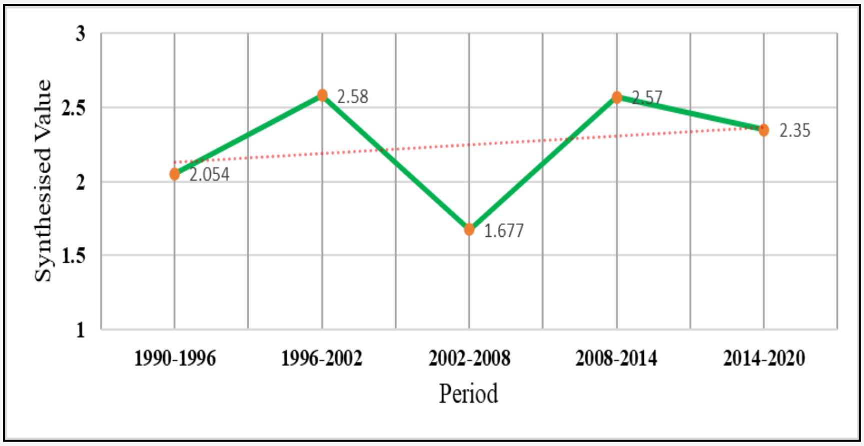


Figure 7: Annual rate of synthesized Land Use/ Cover (%) 1990 – 2020

3.4 Dynamic Changes in Single and Synthesized Land Use/ Cover

Using the simplex model of land use dynamic degree, quantitative change is calculated in a certain kind of land use type in the study area annually. From equation 1 and the values of Table 2, it is possible to calculate the simplex land-use type dynamic changes from 1990 to 2020 every six years, as shown in Figure 6. In Figure 6, the yearly change rate of six kinds of land use in Northern Province throughout six time periods (1990-1996, 1996-2002, 2002-2008, 2008-2014, 2014-2021, and 1990-2020) can be seen in six different periods. Between the years 1990 and 2020, the dynamic change of dense forest, water bodies and barren land is in negative value, indicating that the gross area of these lands is decreasing year after year, and the decrease rates are 1.68%, 1.12% and 0.71% respectively; the dynamic change of agriculture, homestead and scrub are all present in positive value, indicating that the gross area of these lands is fleetingly increasing annually, and the increase rates are 1.81%, 2.73% and 1.56%, respectively. From 1990 to 2020, a total of 4381 Km^2 of land in the study area experienced land-use changes, and the annual rate of synthesized land use dynamic change increased from 2.05% in the 1990–1996 period to 2.35 % between 2014–2020.

Table 3: Land use/ cover vulnerability 1990 -2020

Land Use/ Cover Type	1990	2020	Gain	Loss	Persistence	Gp	Lp	Np
Agriculture	16.88	26.04	14.31	5.15	11.73	1.22	0.44	0.78
Barren land	3.60	2.83	2.46	3.23	0.37	6.65	8.73	-2.08
Dense forest	47.71	23.64	1.93	26.00	21.71	0.09	1.20	-1.11
Homestead	16.29	29.62	17.60	4.27	12.02	1.46	0.36	1.10
Scrub	9.39	13.79	12.43	8.03	1.36	9.14	5.90	3.24
Water bodies	6.13	4.07	0.55	2.61	3.52	0.16	0.74	-0.58

However, synthesized land use dynamic change is 2.58% in 1996- 2002, 1.677% in 2002 – 2008, and 2.57% in 2008 – 2014 (Figure 7).

3.5 Land Use/ Cover Vulnerability

The vulnerability of land use/ cover is determined based on the percentage of the transition matrix's values. Table 3 shows the values for area, gain, loss, and persistence extracted from the transition matrix between 1990 and 2020. Accordingly, the net change-to-persistence (Np) value is positive for agriculture, scrub, and homestead, these land use/ cover have the highest probability of gaining from other land use/ cover classes. The net change-to-persistence (Np) value appeared as negative for barren land, dense forests, and water bodies. This means that these land use/ cover classes would have a higher probability of losing their current area and converting to other land use/ cover classes than gaining from them. Dense forests, barren land, and water bodies have a more vulnerable nature to change because of anthropogenic activities such as land encroachment, resettlement, agricultural expansion, and urbanization. Consequently, wildlife habitat decreases or degrades, and wild animals move into the human settlement and agricultural areas, which causes rising human-wildlife conflict in the Northern Province.

4. Conclusion

This research identifies changes in the land use/ cover of the Northern Province. Several techniques, such as spatiotemporal analysis, change matrix, dynamic degree of land use/ cover change, synthesized land use/ cover annual change and vulnerability analysis, have been used to quantify large-scale land use change. Hence, there have been significant changes in land use/ cover in the Northern Province between 1990 and 2020. Specifically, the forest has been removed, and new settlements, agricultural activities, and homesteads have expanded. Forest lands have declined over time, whereas residential and agricultural lands have increased. As a result of the thirty-year civil war and more than ten years of accelerated reconstruction and agricultural and other development processes, the Northern Province underwent significant changes in land use. Even after the conflict's conclusion in 2009, illicit sand mining and indiscriminate commercial logging continued, causing significant changes in land use/ cover. This study disclosed precise quantitative and qualitative information about the land use/ cover change in Northern Province. This information will be essential for any spatial planning, particularly land use planning activities of the Northern Province of Sri Lanka. In addition, decision-makers involved in development will benefit from comprehensive land use data.

Such research will raise land use knowledge among land users, development planners, and ecologists alike. It will also suggest the necessity for zoning for land use. This kind of research will also aid in the development of land-use planning regulations and policies. It will also give information on land uses that are diminishing and must be conserved. Undoubtedly, this research will provide valuable guidance to planners, development operators, and ecologists when making decisions on land use.

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