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Research Article

Multidecadal Land Use Patterns and Land Surface Temperature Variation in Sri Lanka

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Agricultural land conversion due to urbanization, industrialization, and many other factors is one of the significant concerns to food production. Therefore, analyzing the temporal and spatial variation of agricultural lands is an emerging topic in the research world. However, an agrarian country like Sri Lanka was given weaker attention to the temporal and spatial variation of the land use, including the agricultural lands. This study presents an extended analysis of temporal and spatial variation of land use patterns in Sri Lanka, specifically looking at the agricultural land conversion and land surface temperature (LST) change. Remote sensing techniques and geographic information system (GIS) were used for the presented work. The satellite images from three Landsat's were analyzed for 2000, 2010, and 2020 to identify the potential land use conversions. In addition, LSTs were extracted for the same period. Significant and continuous increases can be seen in the agricultural lands from 33.94% (of total area) in 2000 to 43.2% in 2020. In contrast, the forest areas showcase a relative decrease from 38.51% to 33.82% (of total area) during the analyzed period. In addition, the rate of conversion from agriculture to settlements is higher in the latter decade (2010–2020) compared to the earlier decade (2000–2010). Only general conclusions were drafted based on the LSTs results as they were not extracted in the same months of the year due to high cloud cover. Therefore, the results and conclusions of this study can be effectively used to improve the land use policies in Sri Lanka and lead to a sustainable land use culture.

1. Introduction

Food production is mainly based on land agriculture. Therefore, land use changes are vital in achieving today's and tomorrow's food demand. In addition, all other essential activities can be influenced by changes in land use. On the other hand, the economic growth of a country is directly subjected to land use [1]. Therefore, land use patterns are fundamental and should be critically analyzed. Land use and land cover change (LULCC) is a significant influencer in all activities [2]. In addition, it is unavoidable and unstoppable due to economic development and population growth [3].

Economic activities are often bound to changes in land use. Chen et al. [4] presented the relationships between economic developments and land use and land cover change using satellite images. They have validated the approach to Zhoushan City, China. In addition, economic development policies and changes in land use were detailed and discussed in Thailand by Tontisirin and Anantsuksomsri [5]. They have clearly stated the challenges in urban administration and management in Thailand's agricultural culture. Similar studies can be seen in the literature for different regions and countries based on their importance [6–9].

Land use patterns and changes are highly dependent on population growth. Human settlements have cleared more forest covers. In addition, their need for food production has increased the agricultural lands. On the other hand, some agricultural lands are regionally converted to human

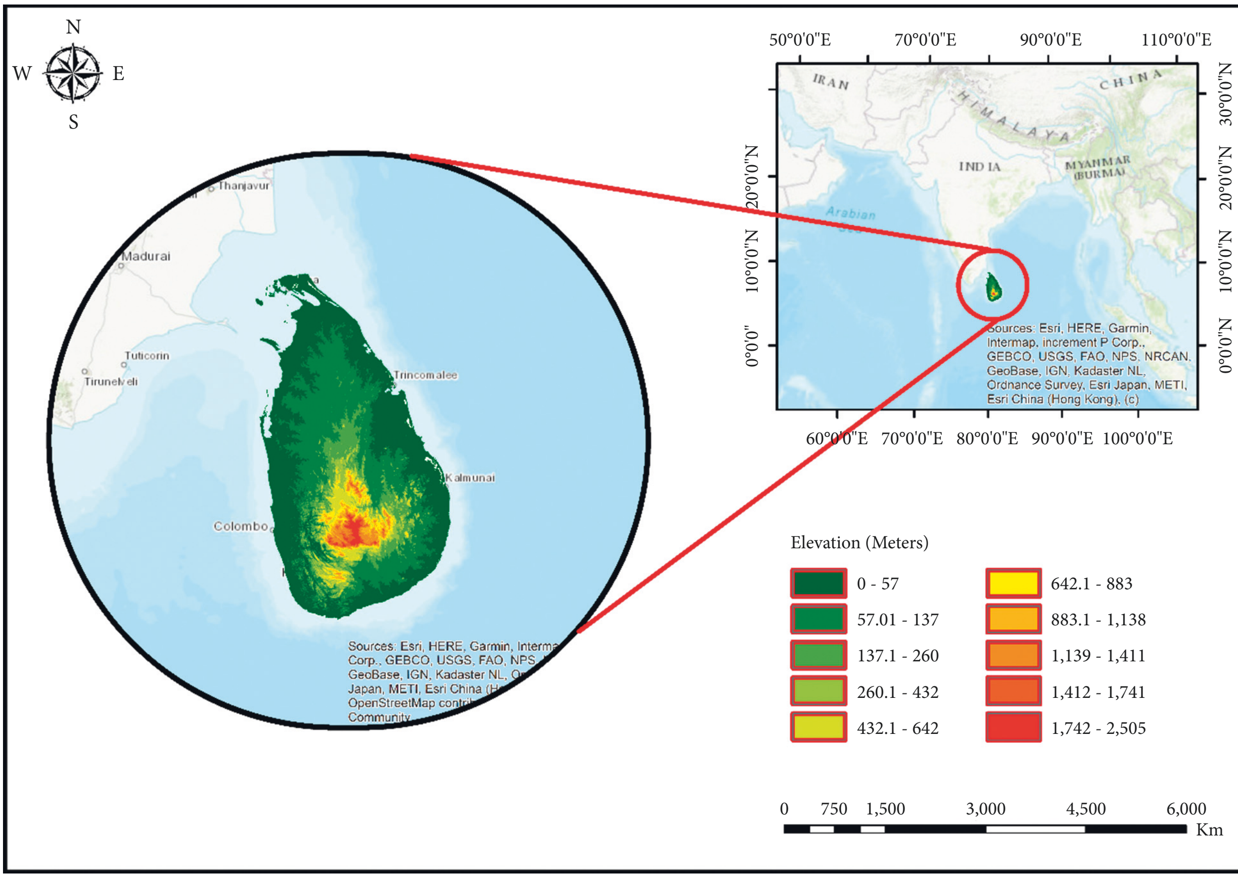


Figure 1: Study area of the research and its topography.

settlements. Therefore, food production is under threat. Usually, the highest agricultural land conversion rate can be seen in developing countries [10].

Globally, countries such as China, Japan, and the USA have identified the adverse impact of agricultural land conversion. They have tried to implement new policies and rules to protect agricultural lands from other uses [11]. Agricultural land conversion has rapidly happened in China since 1980 due to high population, rapid economic growth, and urbanization. However, the authorities have identified a loss of more than two-thirds of cultivated areas in China by 1995. The agricultural land conversion rate in the Netherlands was 17 ha per day from 1996 to 2000, whereas it was 114 ha in Germany in 2006 [10]. Developing countries such as China and Indonesia had an agricultural land conversion rate of 802 ha in 2004 [3] and 514 ha per day in 2000–2002 [12].

Additionally, agriculture has been impacted by climate variables other than LULC. Temperature, humidity, precipitation, and day length significantly impact agricultural and food production [13, 14]. For instance, over two-thirds of land will be lost in Africa by 2025, while agricultural productivity will decline from 21% to 9% by 2080. According to Liliana [15] and Masipa [14], this will put almost nine billion people at risk of food scarcity by 2050. As a result, worldwide hunger will be a significant issue, particularly in sub-Saharan Africa and South Asia, where climate change will result in severe food shortages by 2080 [16–18].

Due to population growth and economic competitiveness, the world has seen rapid and unplanned urbanization, resulting in a continual increase in temperature, affecting agricultural and food production. Population growth has a considerable effect on changes in LULC [19–21]. LULC changes directly impact ecosystems and habitats, significantly increasing land surface temperature (LST) and enhancing the effects of climate change [22–24]. The relationship between LST and land use/land cover (LULC) types is now well established [25]. The amount of surface water and vegetation (forest lands) covered affects the partitioning of sensible and latent heat fluxes and, therefore, the LST response [26]. Therefore, to accomplish comprehensive urban development that is environmentally sustainable in terms of agricultural yields and environmental sustainability, it is necessary to analyze advances in LULC and LST.

In the late 1970s, Sri Lanka implemented an open economic strategy [27]. The country's socioeconomic and political activities have been drastically changed since then. These policy changes have resulted in the introduction of many multipurpose developments projects, such as river basin development initiatives dated back to the 1980s, transportation and highway development projects, and the expansion of agriculture and existing urban centers

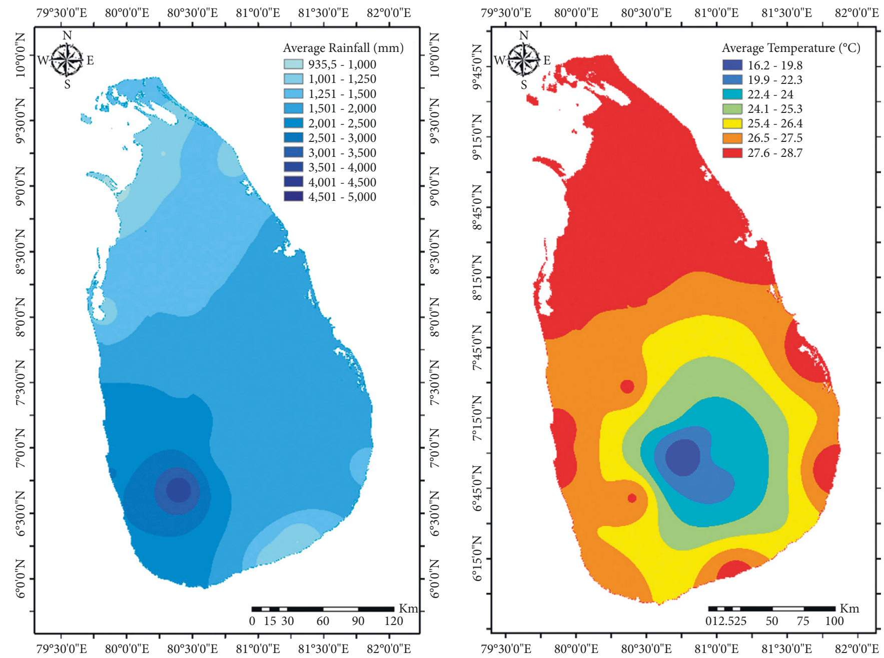


Figure 2: Spatial variation of (a) annual rainfall and (b) annual mean temperature in Sri Lanka.

[28–30]. In addition, the country's northern and eastern parts were severely affected due to the war, which happened for 30 years from 1980 to 2009. Not only these regions but the whole country was under a more significant economic recession due to this war. Therefore, Sri Lanka was one of the lowest economic developing countries in the south Asian region [31, 32]. However, the country caught up after the war in 2009, and the LULC map has been drastically changed.

Nevertheless, sound conclusions cannot be established due to the absence of large-area LULC change studies for Sri Lanka. In addition, temporal comparisons of LULC maps were unavailable for Sri Lanka. Therefore, the quantification of land use change is yet to be explored [33–35]. However, Rathnayake et al. [36] presented notable research work on land use land cover change in Sri Lanka using Landsat time series maps from a forest model. However, the study was not focused on agricultural land conversion. In addition, the interactions of land surface temperatures (LST) were not incorporated by Rathnayake et al. [36].

On the other hand, the integration of recent advances in computer technology and the availability of freely accessible open-source data like the United States Geological Survey (USGS) Earth Explorer with remote sensing techniques has become an ideal source for land use mapping [37]. Therefore, capturing of consistent and temporally varied satellite images at an appropriate spatial scale for both natural and human-induced land use scenarios such as deforestation, urbanization, and agriculture is highly possible [38–41].

Therefore, this study provides a detailed analysis of the LULC variation to identify the land use patterns and

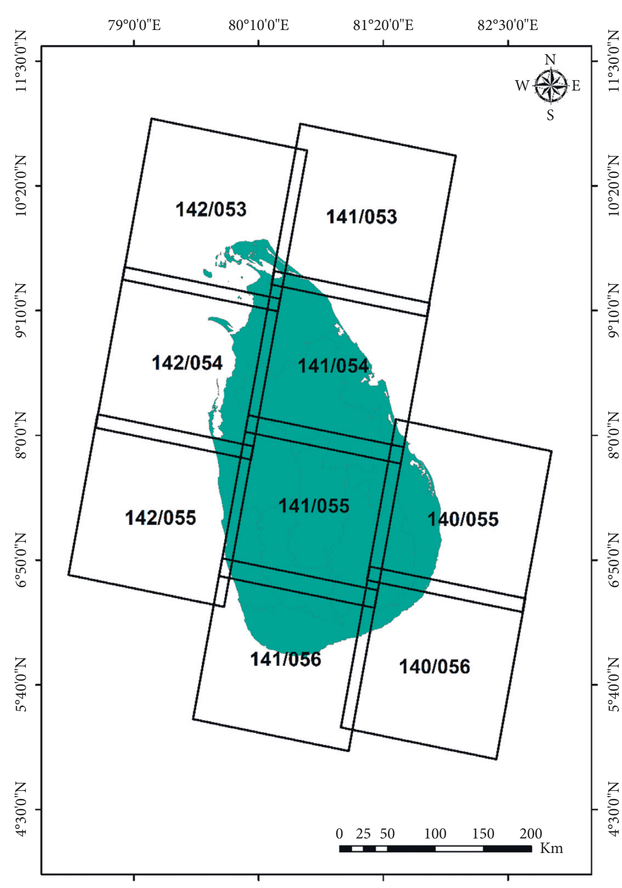


Figure 3: Landsat tiles arrangement of Sri Lanka.

Table 1: Dataset information on sensors and bands.

Year	Satellite name	Sensor ID	Path/row	Acquisition date	Cloud cover (%)
2000	Landsat 7	ETM+	142/053	28-10-2000	2
			142/054	15-12-2000	7
			142/055	15-12-2000	0
			141/053	17-07-2000	8
			141/054	06-09-2001	0
			141/055	14-03-2001	4
			141/056	14-03-2001	2
			140/055	28-09-2000	0
			140/056	28-09-2000	0
2010	Landsat 5	TM	142/053	16-10-2010	1
			142/054	25-07-2009	5
			142/055	18-02-2010	0
			141/053	03-06-2010	1
			141/054	13-11-2011	3
			141/055	04-11-2008	4
			141/056	26-01-2010	2
			140/055	09-06-2009	1
			140/056	28-08-2009	1
2020	Landsat 8	OLI/TIRS	142/053	07-07-2020	0.7
			142/054	07-07-2020	2.1
			142/055	07-07-2020	1.9
			141/053	04-10-2020	5
			141/054	29-03-2021	0.4
			141/055	13-07-2017	3
			141/056	09-02-2021	2.7
			140/055	03-03-2020	3.2
			140/056	03-03-2020	0.6

its statistics in Sri Lanka over the last two decades (from 2000 to 2020). The freely available United States Geological Survey (USGS) Earth Explorer satellite images were used in this study. In addition, LST analyses were carried out in Sri Lanka to observe the variation over the two decades.

2. Materials and Methods

2.1. Study Area. As stated in the introduction, Sri Lanka was not explored for its agricultural land conversion in previous research. Therefore, the "Pearl Island" in the Indian Ocean, Sri Lanka (7.8731°N, 80.7718°E) was selected for this study (Figure 1). Sri Lanka is an agrarian island with approximately 65, 525 km^2 and about 21.8 million people [42]. Due to the country's hilly topography and vast river flow network, which spans most of the country, the country offers a unique but diverse environment. The country can be generally categorized into three distinct regions based on topography: the central highlands, plains, and coastal belts. There are agricultural fields in every region. For example, one of the most important export products, tea, can be found in the central highlands. There are also vegetable lands that produce carrots, cabbage, etc. Similarly, paddy fields, cornfields, and other vegetable and seeds fields can be found in plain and coastal areas. The elevation of the Central Highlands varies from 432 to 2500 m, as shown in Figure 1.

The climate in Sri Lanka is categorized into four seasons (first intermonsoon, southwest monsoon, second intermonsoon, and northeast monsoon) with two major monsoonal seasons (southwest monsoon and northeast monsoon). The southwest monsoon usually occurs from May to September, whereas the northeast monsoon happens from December to February. The mean annual rainfall varies from 900 mm to 5000 mm, maximizing it on the western slopes of the central highlands. Figure 2(a), extracted from The Department of Meteorology, Sri Lanka, shows the spatial variation of rainfall. The temperate atmospheric variation over Sri Lanka is shown in Figure 2(b). It showcases a variation of mean annual temperatures from 27°C in the coastal belt to 16°C in the central highlands [43].

Table 2: Evaluation of LULC classification accuracy.

Years	2000	2010	2020
Overall accuracy (%)	85	87	90
Kappa coefficient (%)	81	84	88

Table 3: ETM+ and TM band-specific thermal conversion constants.

Sensor	Constant 1-k_1 (watts/(m^2 × sr × μm))	Constant 2-k_2 (Kelvin)
Landsat 7 ETM+	666.09	1282.71
Landsat 5 TM	607.76	1260.56

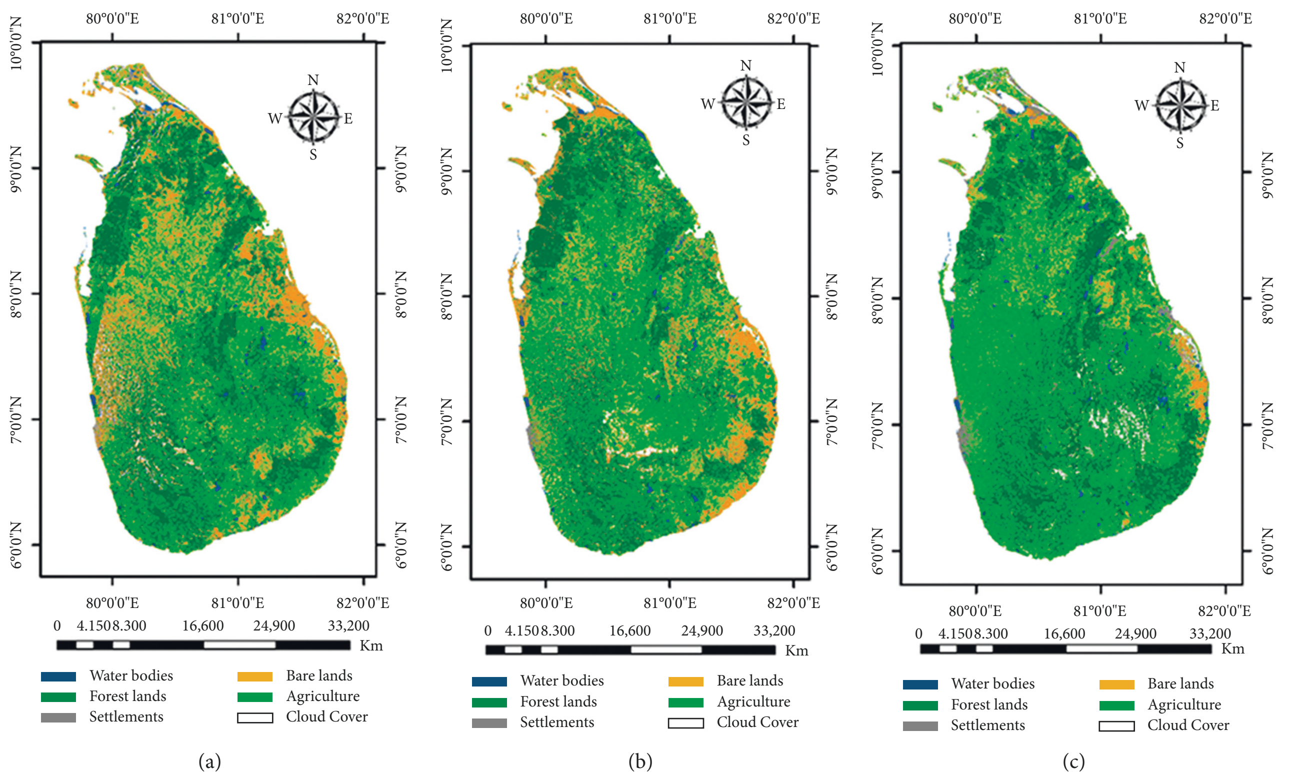


Figure 4: Land use and land cover over the years. (a) For 2000. (b) For 2010. (c) For 2020.

Table 4: Land use and land cover change statistics of Sri Lanka.

LULC type	Area (Km^2)			Percentage (%)		
	2000	2010	2020	2000	2010	2020
Agricultural	22570.65	25481.12	28728.90	33.94	38.32↑	43.20↑
Forest lands	25606.17	24216.66	22490.17	38.51	36.42↓	33.82↓
Bare lands	13677.18	11879.90	7930.15	20.57	17.87↓	11.93↓
Settlements	2157.91	2716.09	4868.51	3.25	4.08↑	7.32↑
Water bodies	1907.88	1576.76	1582.22	2.87	2.37	2.38

2.2. Landsat Data. Landsat images for Sri Lanka were obtained from the United States Geological Survey (USGS) Earth Explorer (https://earthexplorer.usgs.gov/). These Landsat images are in the raster format with a 30 m × 30 m resolution. Remote-sensed Landsat images from 2000 to 2020 were extracted with a ten-year interval (2000, 2010, and 2020) from Landsat 5 TM, 7 ETM+, and Landsat 8 OLI. The Landsat 5 TM images were available from 1984 to 2012; however, cloud-free Landsat 5 TM images were unavailable for 2000. Therefore, Landsat 7 ETM+, available from 1999 to 2003, was used for 2000 analysis. 27 Landsat images were used for the research, including nine Landsat tiles covering Sri Lanka. These tiles are shown in Figure 3. These images were either cloud-free or with less than 10% cloud cover. However, few satellite images had higher cloud cover (>10%). This issue may produce some errors for the actual condition, which is a potential limitation of this study. Therefore, the nearest years' Landsat images (cloud-free or cloud cover less than 10%) were taken in these cases. Thus, the effect of cloud cover in the analysis was kept at a minimum.

Table 1 provides a summary of the satellite images extracted for this study. The images are shown against the satellite name, acquisition date, and cloud cover.

2.3. Land Use and Land Cover Classification. High-resolution satellite images from the Google Earth simulator were used to classify the land use classes of the study area. The classification was conducted for six land use classes, including water bodies, forest lands, settlements, bare lands, agriculture, and cloud cover, with a nonparametric supervised classification method. Land use classes are derived based on an effective land use classification system developed by the United States Geological Survey (USGS). Additional information is available in Anderson et al. [44]. ArcGIS 10.4.1 was incorporated for this classification. According to Lillesand et al. [45]

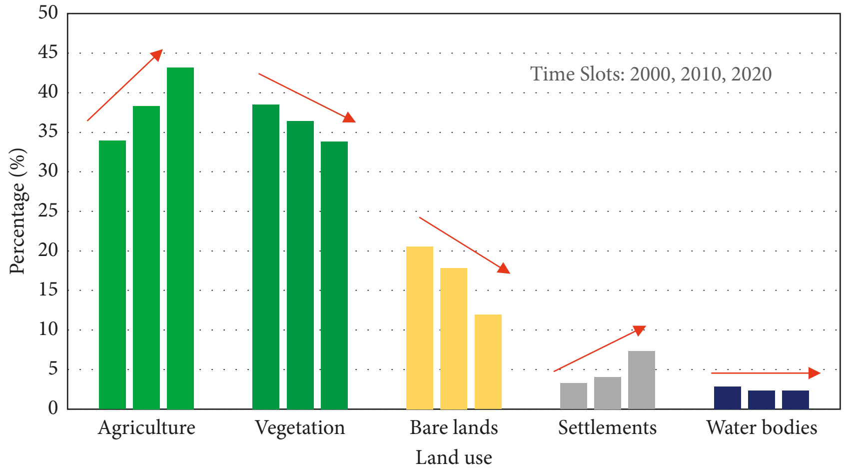


FIGURE 5: Land use and land cover change statistics of Sri Lanka.

standards, training samples and pixels were assigned to each land use class.

The supervised classification was applied to generate the LULC map in 2000, 2010, and 2020 with high accuracy, as given in Table 2. The goal of accuracy evaluation is to see how successfully pixels were sampled and classified into proper land cover groups. Furthermore, areas easily visible on Landsat high-resolution images, Google Earth, and Google Maps were prioritized in the accuracy evaluation pixel selection process. A total of 300-pixel points were produced in the classified image of the research region by following the minimum sample size of 50 samples for each class [46]. KAPPA analysis is based on a discrete multivariate technique used to evaluate accuracy. It produces a Khat statistic, a measure of accuracy [47]. The Khat is determined as follows:

$$K = \frac{N \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} \times x_{+i})}, \quad (1)$$

where N is the total number of observations in the matrix, r is the number of rows and columns in the matrix, x_{ii} is the number of observations in row i and column i, x_{i+} is the marginal total of row i, and x_{+i} is the marginal total of column i.

2.4. Retrieval of Land Surface Temperature

2.4.1. Retrieval of Land Surface Temperature from Landsat 5 and Landsat 7. Thematic Mapper (TM), thermal band (band 6), and Enhanced Thematic Mapper Plus (ETM+) thermal band (band 6) were used to retrieving the land surface temperature. The digital numbers (DNs) of band six were converted to spectral radiance (L_λ). The governing equation is given in equation (1).

$$L_\lambda = \frac{L_{\max} - L_{\min}}{Q_{\max} - Q_{\min}} \times (Q_{\text{cal}} - Q_{\min}) + L_{\min}, \quad (2)$$

where L_λ is the spectral radiance at the sensor's aperture, $L_{\max}$ is the spectral radiance that is scaled to QCALMIN $(\text{watts}/(\text{m}^2 \times \text{sr} \times \mu\text{m}))$, $L_{\min}$ is the spectral radiance that is scaled to QCALMAX $(\text{watts}/(\text{m}^2 \times \text{sr} \times \mu\text{m}))$, Q_{cal} is the quantized calibrated pixel value in DN, $Q_{\max}$ is the maximum quantized calibrated pixel value in DN, and $Q_{\min}$ is the minimum quantized calibrated pixel value in DN.

Then, the spectral radiance (L_λ) was converted to at-satellite brightness temperature (T (°C)) using equation (2) [48].

$$T\,(°\text{C}) = \frac{K_2}{\ln((k_1/L_\lambda) + 1)} - 273.15, \quad (3)$$

where k_1 and k_2 are the band-specific thermal conversion constants, which can be obtainable from Table 3. It presents k_1 and k_2 values for Landsat 7 and Landsat 5.

2.4.2. Retrieval of Land Surface Temperature from Landsat 8. Operational Land Imager (OLI) and thermal infrared sensor (TIRS) thermal band (band 10) were used to retrieve land surface temperature from Landsat 8. The conversion of DN values of Landsat datasets into absolute radiance values was done using equation (3) [49].

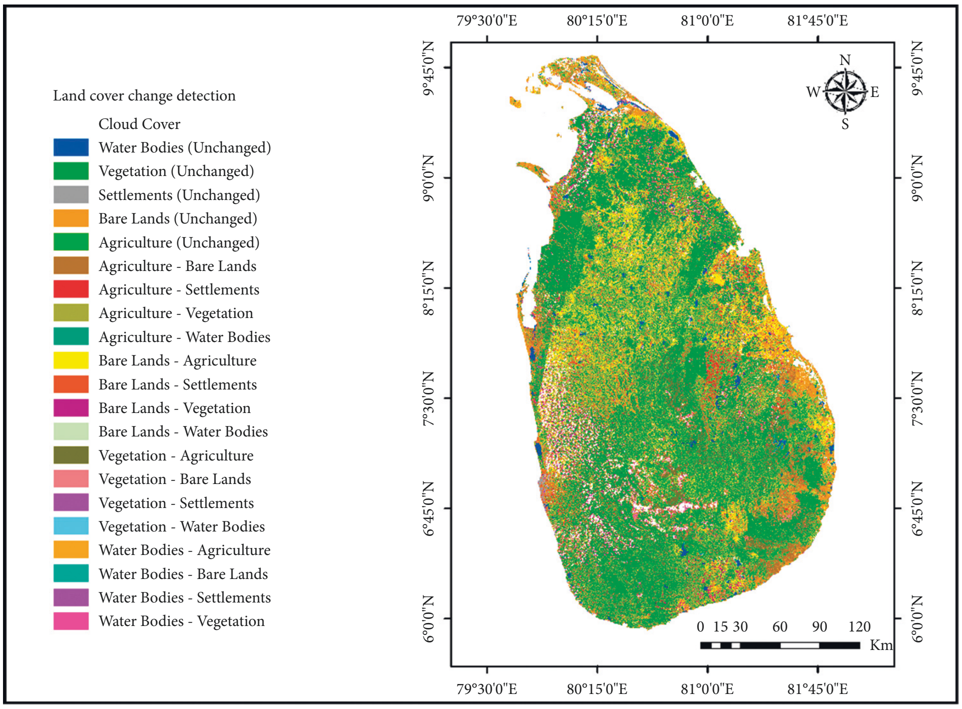
$$L_\lambda = M_L \times Q_{\text{cal}} + A_L, \quad (4)$$

where L_λ is the spectral radiance $(\text{watts}/(\text{m}^2 \times \text{sr} \times \mu\text{m}))$, M_L is the radiance multiplicative scaling factor for the band, A_L is the radiance additive scaling factor for the band, and Q_{cal} is the level 1 pixel value in DN.

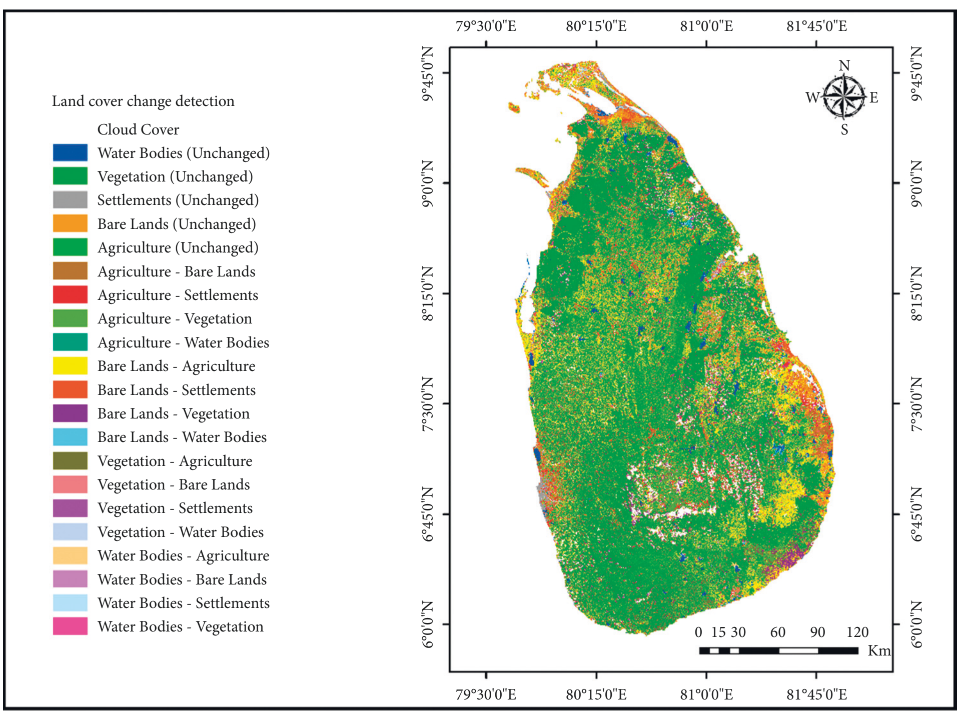
Then, the radiation luminance was converted into satellite brightness temperature in Celsius, T_B (°C), using the following equation (4).

$$T_B\,(°\text{C}) = \frac{k_2}{\ln((k_1/L_\lambda) + 1)} - 273.15, \quad (5)$$

where $k_1 = 774.8853$ $(\text{watts}/(\text{m}^2 \times \text{sr} \times \mu\text{m}))$ and $k_2 = 1321.0789$ Kelvin. The brightness temperature was used to calculate the emissivity corrected LST and shown in equation (5) [50].



(a)



(b)

Figure 6: Land use and land cover change. (a) From 2000 to 2010. (b) From 2010 to 2020.

$$\mathrm{LST}\,(^{\circ}\mathrm{C}) = \frac{T_B}{1 + (\lambda \times (T_B/\rho))\ln \varepsilon}, \tag{6}$$

where, T_B and λ are the Landsat 8 band 10 brightness temperature and wavelength of emitted radiance ($\lambda = 10.8\,\mu$m), respectively. Various coefficients such as $\rho = h \times c/\sigma$ (1.438×10^{-2} mK), σ = Boltzmann constant (1.38×10^{-23} J/K), h = Planck's constant (6.626×10^{-34} Js), and c = velocity of light (2.998×10^{8} m/s) are also used in equation (5). The land surface emissivity (ε) was estimated using equation (6) [51, 52].

$$\begin{aligned}
\varepsilon &= mP_v + n, \\
m &= (\varepsilon_v - \varepsilon_s) - (1 - \varepsilon_s)F\varepsilon_v, \\
n &= \varepsilon_s + (1 - \varepsilon_s)F\varepsilon_v,
\end{aligned} \tag{7}$$

where ε_s and ε_v are the soil emissivity and vegetation emissivity, respectively. P_v in equation (6) is the vegetation proportion and was derived using equations (7) and (8) [53].

$$\begin{aligned}
\text{NDVI} &= \frac{\text{NIR} - \text{red}}{\text{NIR} + \text{red}}, \\
P_v &= \left(\frac{\text{NDVI} - \text{NDVI}_{\min}}{\text{NDVI}_{\max} - \text{NDVI}_{\min}}\right)^2,
\end{aligned} \tag{8}$$

where NDVI is the normalized difference vegetation index.

3. Results and Discussion

3.1. Land Use and Land Cover Changes in Sri Lanka. The overall accuracy was consistently above 85%, while the Kappa coefficient was 80%. Therefore, the quality of the developed maps is of higher accuracy.

Figure 4 shows the temporal variation of LULC of Sri Lanka in 2000, 2010, and 2020, respectively. It shows the reduction of bare lands in the country (especially towards the eastern and northwestern sides of the country). Therefore, these show a good indication of the land use change over the years in Sri Lanka. In addition, the forest lands in the northern part of Sri Lanka were significantly reduced over the years. As stated in the introduction, the war in these two regions' north and eastern parts ended in 2009. This could be a reason for the significant land uses in these two regions. Nevertheless, land uses can be seen for the whole country.

The land use and land change areas as numerical values and percentages over the total areas are given in Table 4. The arrows (↑, ↓) in the table reflect the rise or drop in percentages. The agricultural lands took the highest proportion of the country at 33.7% in 2000; however, a significant increase can be seen from 2000 to 2010 and then from 2010 to 2020. This is verified by FAO United Nations [54]. This showcases the food demand in the country due to population growth (population in Sri Lanka—18.78 M in 2000, 20.26 M in 2010, and 21.8 M in 2019). Therefore, a gradual increase in inland areas for settlements can be identified, while drops can be observed in forest and bare lands.

The land use and land change percentages are visually shown in Figure 5. It clearly showcases the rises and drops and the rates. Interestingly, the areas for water bodies remain constant (roughly), which is a good sign in the context of water availability.

3.2. Land Use and Land Cover Change Detection Statistics in Sri Lanka. Land cover conversion for different land cover categories is shown in Figure 6. The legend's initial sectors (the first five sectors—water bodies, forest lands, settlements, bare lands, and agriculture) showcase the unchanged land uses. However, the color codes present the changes from one land use to another in a decade. Figure 6(a) shows these changes from 2000 to 2010, while Figure 6(b) shows them from 2010 to 2020. Explicit land use conversions can be seen from agriculture to settlements (red patches) in Figures 6(a) and 6(b). In addition, significant transformations can be seen from bare lands to agriculture (yellow patches) in both decades.

Table 5: Agricultural land cover conversion statistics of Sri Lanka.

Conversion	Area (Km^2)	
	2000–2010	2010–2020
Agriculture to settlements	485.13	1536.28
Agriculture to bare lands	4631.89	1322.12
Agriculture to forest lands	5220.31	7793.39
Agriculture to waterbodies	198.87	184.50
Bare lands to agriculture	6030.92	6401.28
Forest lands to agriculture	6492.78	6172.59
Water bodies to agriculture	317.35	148.61

These agricultural land use conversions are numerically given in Table 5. Notable land use and land cover conversions, as shown in Figure 6, are suggested here. Agriculture to settlement land use conversions were 485.13–1536.28 km^2, respectively, from 2000 to 2010 and 2010 to 2020. However, significant land use conversions can be found from bare lands to agricultural lands and forest lands to agricultural lands in both decades, and they are around 6000 km^2. Population growth and finishing the civil war can be two possible reasons for these land use conversions. Land use conversions in water bodies could be due to the construction of new reservoirs (like Moragahakanda reservoir).

3.3. Land Usage Types and Land Surface Temperature. Land surface temperatures for 2000, 2010, and 2020 are graphically shown in Figure 7. These LSTs are not for the same month of the year; therefore, comparing years is impossible. Due to cloud cover, the LSTs could not obtain for the same month in 2000, 2010, and 2020.

The land surface temperature analysis reveals that the mean LSTs in settlement (29.93°C, 24.77°C, and 23.63°C) and bare land (30.62°C, 26.75°C, and 26.68°C) areas are higher than the areas with forest lands (26.46°C, 24.72°C, and 21.89°C) and water bodies (25.02°C, 23.96°C, and 21.65°C) in 2000, 2010, and 2020, respectively. This observation is justifiable as forest lands and water bodies would have reduced land surface temperatures. Therefore, to have a more significant comparison of LSTs for the land use and land cover conversion, much better satellite images should be temporally obtained simultaneously. Nevertheless, the pattern can be assumed for the land use conversions from the above-stated results. When there is a land use change from forest lands to agricultural land, an increase in LSTs can be expected. Therefore, these increased LSTs can adversely impact the surroundings. Similarly, conversion from agricultural land to a water body may decrease LSTs. Thus, the ecological aspects may have to consider.

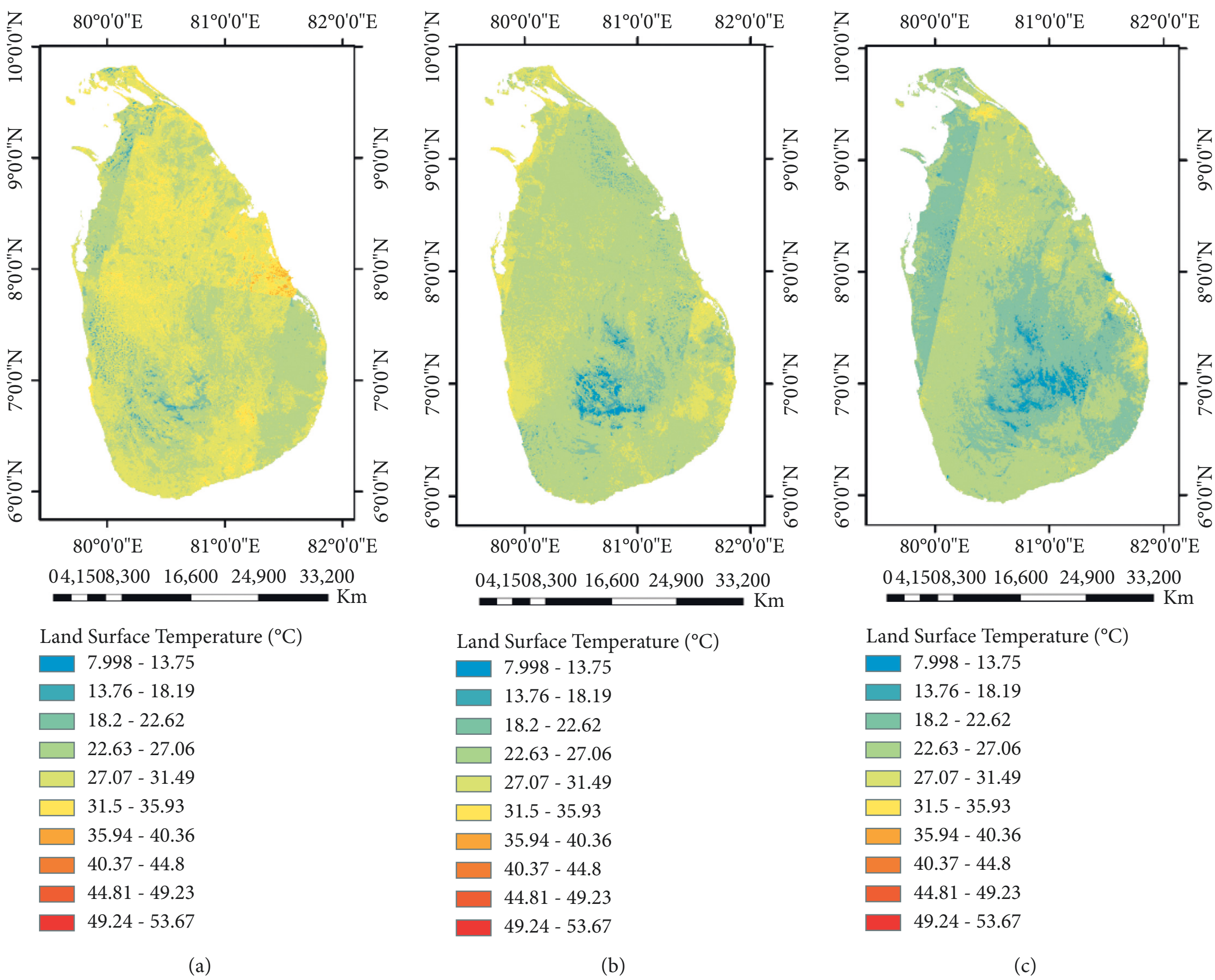


Figure 7: Land surface temperatures (LST) over the years. (a) For 2000. (b) For 2010. (c) For 2020.

4. Conclusions

This study reveals the impact of land use and land cover change (LULCC) and land surface temperature (LST) variation for the past 20 years in Sri Lanka. The results showcase the increase of agricultural lands up to 43.2% in 2020, which is a positive sign for the food production and agricultural economy perspective of Sri Lanka. However, with the increment in agricultural land use and settlements, it is evident that there is a reduction of forest lands in the country. This can adversely impact the natural rainforests and other forests, like the Sinharaja forest.

The change detection analysis of this study summarized the areas converted during the past 20 years. Therefore, the deforested areas can be easily identified. General conclusions can be driven from the LST analysis as they were not in the same months of the years. However, it can be clearly seen that the LSTs are lowered for water bodies and forest areas, while settlements have some higher LSTs. Therefore, some projections can be drafted on land use conversions. Forest areas are in the reducing passage, and consequently, it can be expected to see higher LSTs. This can lead to many environmental and ecological issues in Sri Lanka. Nevertheless, for sound conclusions on LSTs, a detailed and comprehensive analysis may have to carry using better satellite images (may be from nonfree satellites). With these concluding remarks, this research can be well used to develop new policies to protect the available land uses while keeping the sustainable usage of land resources.

Data Availability

The data used to support this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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