REGION
The Journal of ERSA
Powered by WU

Volume 13, Number 2, 2026, 81–100
DOI: 10.18335/region.v13i2.642

journal homepage: region.ersa.org
ISSN: 2409-5370

Spatiotemporal Assessment of Expressway-Induced Land Cover and Landscape Transformation in Sri Lanka

Piyoda Wijesekara[1,2], Amila Jayasinghe[2]

[1] University of Sri Jayewardenepura, Nugegoda, Sri Lanka
[2] University of Moratuwa, Moratuwa, Sri Lanka

Received: 20 October 2025/Accepted: 24 June 2026

Abstract. Since the twentieth century, the sustainable use of land has emerged as a critical concern, with land use patterns shifting rapidly from agricultural and settlement expansions to infrastructure and urban development. Transport infrastructure is tightly connected to urban expansion, while exerting both positive and negative impacts on land, society, the economy, and biodiversity. In addressing the need for sustainable land management, land cover change detection studies offer valuable insights that help scholars and policymakers to overcome contemporary challenges in environmental conservation. This study focuses on the Southern Expressway Development Project (STDP) of Sri Lanka, where large-scale linear development projects represent a relatively new phenomenon. The study detects changes within a 5 km buffer zone of the first phase of the STDP between the period 2001-2021, utilizing Geographic Information System (GIS) and Remote Sensing (RS) techniques. ArcGIS 10.8 and FRAGSTATS 4.2 were mainly used for the analysis, using Landsat 7 and 8 images for both years. Seven land classes were identified using supervised image classification. The overall accuracy of both images was 84% in 2001 and 85% in 2021. The analysis showed that natural vegetation and built-up land cover increased significantly, while cultivated lands, paddy and homesteads decreased by 5%, 7.73% and 6.44%. Water areas did not exhibit significant change during the study period. The Transfer Matrix depicted that 11066.14 ha of cultivated lands were transferred to natural vegetation. A large area of paddy lands was converted into cultivated land (8,530.64 ha) and natural vegetation (7,218.78 ha). Results obtained through FRAGSTATS analysis revealed that the patch density of the total area was increased from 112.57 to 169.42 and the number of patches of the overall landscape was increased by 58459. Although natural vegetation and urban land increased in total area, both land uses were highly fragmented according to the class-level analysis. The area means of all the land uses were reduced. Introducing agricultural land protection zones, regulating urban expansion, promoting high-value crops, agroforestry, and climate-resilient farming practices are some of the recommendations to reduce the effect of landscape change and fragmentation. The findings are valuable for urban planners on two fronts. On one hand, the study provides a quantitative analysis of the impact of STDP on land use and land cover changes. On the other hand, the GIS & RS-based methodological framework would be useful for urban and regional planners in assessing land use changes and fragmentation associated with large-scale infrastructure development.

Key words: Urban and Regional Planning, Land Cover Change, Land Fragmentation, Temporal and Spatial change

1 Introduction

Humans and nature are intimately intertwined through land cover and land use. Research on sustainability and global environmental transformation has identified land as a key resource that is changing rapidly. By comprehending the dynamics of land cover as a connected human-environment system, this discipline addresses theories, applications, principles and models pertinent to environmental, human and social concerns (Turner et al. 2008). In this perspective, land science is an interdisciplinary approach. Human and environmental scientists face a significant challenge in quantifying changes in the land and ecosystems and their effects on global environmental change and sustainability (National Research Council 2001). Thus, population pressure and the enormous demand for land underscore the necessity of sustainable land management practices as land is a non-replenishable resource.

Land cover and use are crucial components for understanding the connections between anthropogenic activities and the environment (Prakasam 2010). Zhao et al. (2020) define forests, grasslands, croplands, soil, water bodies and ice layers as examples of land cover. Furthermore, they note that agriculture, husbandry, and urban development provide examples of land uses on the surface. Emphasizing this, Lu et al. (2014) also elaborate that land use refers to a continuous transformation of the land surface and environment by the communities living on it in order to flourish and survive. The land use pattern of a region provides information on natural conditions, socioeconomic variables, human livelihood patterns, development trends and land conditions that existed in the past. Biophysical resources such as vegetation, water, soil, etc., are directly affected by human-caused changes on the land surface (Oumer 2009). Furthermore, land conversion and modification are identified as the primary drivers of land cover change. Land cover conversion refers to the change of particular land cover to another, while land modification refers to the change in attributes. The landscape is formed based on all the land cover types and characteristics of the whole region (Liu et al. 2020). The consequences of biotic factors (such as fauna, flora and bacteria) and abiotic factors (such as soil, atmosphere and water) and their protracted interactions over time on each other have a direct effect on forming a landscape pattern of a region.

Previously, most land use types evolved as a result of agricultural practices and settlement patterns; however, recent land use changes have increasingly been driven by infrastructure development and urban expansion. The international community has recognized the importance of maintaining sustainable land consumption in line with long-term development goals. Accordingly, Goal 15 of the Sustainable Development Goals, adopted under the auspices of the United Nations, underscores the need to harness synergies to optimize the sustainable utilization of land resources. In the pursuit of sustainable land management and the reduction of environmental degradation, land cover change detection studies offer a robust analytical framework for addressing contemporary challenges. Land cover change studies have been a worldwide focus of intensive and interdisciplinary research for close to two decades. However, land change science has outgrown its adolescent stage but has not yet reached full maturity (Turner et al. 2008). Land cover changes can have both immediate and long-term effects on both natural and anthropogenic environments. These changes can result in significant and often lasting impacts on the ecological and social systems. Land cover change is primarily driven by anthropogenic activities such as urban expansion, agricultural intensification, deforestation, and infrastructure development. In addition, natural processes including climatic variability, wildfires, floods, and geological events contribute significantly to changes in land cover patterns. Urban expansion, particularly infrastructure development, transforms land rapidly while addressing the growing needs of the population.

Transport infrastructure plays a significant role in urban conversions, particularly road development, which generates both significant positive (Liu et al. 2020) and negative impacts on land on different scales. The building and operation of expressways have a significant impact on topography and surrounding land cover types, as well as regional landscape patterns (Zhao et al. 2021). Linear infrastructure disrupts core biodiversity areas, leading to increased edge effects. The isolation of core areas may have adverse effects on biotic environments by disrupting gene flow (Pallag 2000), which may affect badly for biodiversity. Additionally, isolation and land fragmentation occurr as a result of linear infrastructure development and urbanization (Wu et al. 2014). Reduced travel time, reduced traffic congestion, cost reduction for delayed transport, increased fuel efficiency, expanding the fisheries, agriculture, tourism and other industrial activities are some advantages of the expressways.

Extensive research exists globally on mega linear infrastructure projects, such as expressways, to discover ecosystem connectivity (Zhao et al. 2021, Zhan et al. 2026), habitat fragmentation (Alexander, Waters 2000) and vegetation lands (Southworth et al. 2011, Jia et al. 2019, Feng et al. 2021). However, there is limited empirical evidence from island territories like Sri Lanka, where expressway expansion intersects with land management needs. Although there are a very limited number of local studies on land valuation (Gunasekera, Weerakoon 2020, Gomes, Dabare 2018), socioeconomic/environmental factors (Karunathilaka et al. 2021), wildlife (Shiromani et al. 2025) and capacity of the toll gates (Kumari et al. 2015, Sarojini 2014, Amarasinghe 2011, Suresh 2018) no study has specifically focused on the effects of the expressway on land cover change, fragmentation, and landscape level changes. Being the 17^{th} smallest country in Asia, with a land mass of 65,610 km^2, it is crucial to effectively manage the development with sustainable land principles. Jayasinghe (2013) shows that over the last thirty years, planners and regional planners have not predicted the emergence of urban corridors along the main roads in Sri Lanka. Therefore, it is vital to investigate the impact of mega linear infrastructure projects on land cover change, fragmentation, and landscape structural dynamics, as the land is a limited resource for islands like Sri Lanka. This study addresses this gap by applying a comprehensive spatiotemporal and landscape metrics approach to assess the impacts of mega linear development projects in Sri Lanka, providing region-specific insights that contribute to global discussions on sustainable infrastructure planning.

Consequently, this study aims to present a comprehensive insight into land cover change, land fragmentation and changes in landscape patterns over the long term and to explore their possible relationships. This study examines both temporal and spatial changes along the expressway. This assessment is highly significant as the project linked two provinces and three districts of the country. Furthermore, the findings can be used to forecast future circumstances of the proposed network of expressways and existing expressway developments, as well as to provide more effective access road services.

The major objective of the research is to analyze the impact of the Southern Expressway on land cover changes and land fragmentation of the surrounding area. The findings are expected to provide answers to the following research questions,

- What are the temporal and spatial dynamics of land cover changes along the Southern Expressway?
- How does the construction of the Southern Expressway affect land fragmentation in the surrounding area?

This study provides the first comprehensive, corridor-wide assessment of land cover change and landscape fragmentation associated with the Southern Expressway, using a long-term (2001–2021) GIS and remote sensing framework. The results offer both a methodological template and actionable insights for regional planners and infrastructure development policy.

2 Methodology

2.1 Study Area

The Southern Expressway Development Project (STDP) was the first expressway project introduced to the island, marking a significant milestone in establishing the island's planned expressway network (Kumari et al. 2015). The construction of the Southern Expressway was initiated in 2003 and the Kottawa (Makubura) to Galle (Pinnaduwa) (95.3km long) section (phase I) was completed and opened to the public in 2011 (RDA, ND). Later, the expressway was extended up to Mattala in the South and Kadawatha in the North.

This is the first E-class highway on the island and it runs through Western and Southern provinces, where the population density is higher than in the other provinces. The expressway operates as a dual carriageway with a four-lane capacity. Until then, the principal town centers were established along the Galle-Colombo main route parallel to the railway line near the western coast of the island. The main town centers were linked to the expressway with eight toll gates.

Tropical climatic conditions are exhibited in the country with an average annual temperature range between 26.5°C and 28.5°C, and the annual average rainfall ranges from 3,000 to 5,000 millimeters (Department of Meteorology 2025). The elevation of the area ranges from 2 to 30 meters above sea level, to more than 80 meters in some of the higher elevations (Asian Development Bank 2007). The area between Kottawa and Pinnaduwa has recorded a minimal danger of landslides (Road Development Authority 2014). Agriculture dominates the project area. River Kalu, river Gin, river Madu, river Bolgoda, river Benthara are the main natural irrigation lines along the affected area. The direct impact was generated in Southern and Western provinces, while 24 Divisional Secretariat Divisions were affected.

The study is based on the first phase of the Southern Expressway (Kottawa- Galle) which is 95.3 km long, and a 5 km buffer on both sides of the road (dual carriageway was considered as one line for the study). The geographical location of the study site is illustrated in Figure 1. 10 years before opening the STDP to the public and 10 years after opening the STDP were considered for analysis due to the availability of satellite images. Accordingly, this study was conducted between 2001 and 2021.

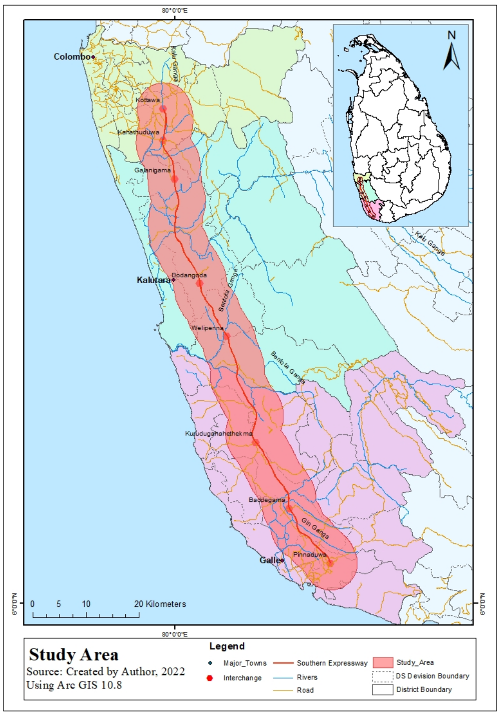

Figure 1: Geographical Location of the Study Area

2.2 Conceptualization

Figure 2 represents the conceptual framework based on the identified factors and the relationship between land cover change and land fragmentation within a dynamic landscape system. Changes in land cover and fragmentation are not independent phenomena; the bidirectional relationship between these components indicates a reciprocal interaction.

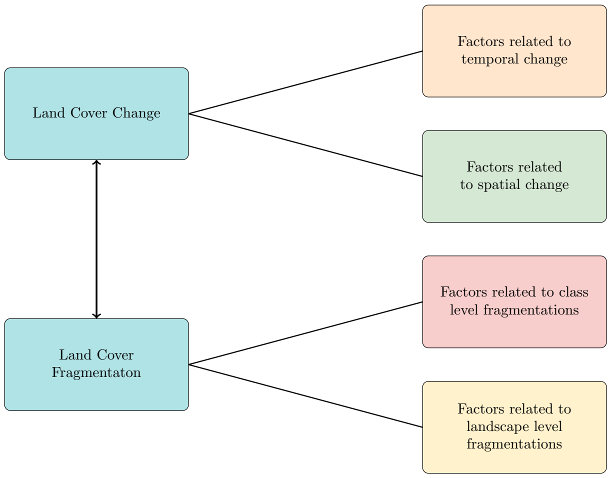

Figure 2: Conceptual framework

Table 1: Sources of Data Collection

	images	row	cover	resolution	date
2001	Landsat 7	path (141) row (055)	3%	30 m 30 m	14th March 2001
	Landsat 7	path (141) row (056)	2%	30 m 30 m	14th March 2001
2021	Landsat 8	path (141) row (055)	3%	30 m 30 m	09th February 2021
	Landsat 8	path (141) row (056)	4.1%	30 m 30 m	09th February 2021

Temporal analysis helps reveal the continuity of land cover dynamics across different time periods while factors related to spatial change focus on the geographical organization and distribution of land cover patterns. By integrating class-level and landscape-level perspectives, the framework provides a comprehensive basis for analyzing landscape dynamics and assessing the environmental consequences of large-scale development and land transformation activities.

The major steps followed are illustrated in Figure 4.

2.3 Data Collection

Satellite images were obtained from the US Geological Survey's Natural Resources Observation Terminal Database website (https://earthexplorer.usgs.gov). All seven bands were downloaded as separate bands and stacked together to generate single image files for 2001 and 2021. Table 1 presents the details of the two image datasets.

2.4 Methods Used

The images were georeferenced to WGS_1984_UTM_Zone_44N which was utilized throughout the analysis. Both images of raw 055 and 056 were merged together to generate a new single layer. Figure 3 depicts both images after layer stacking. This single layer was used to clip out the 5km buffer zone along the first phase of the Southern Expressway (Kottawa- Galle). Unwanted cloud patches that appeared in the images have been removed.

2.4.1 Land Use Classification

Maximum likelihood classification was employed to uncover the LULC of the study area. Before the classification, the Mapping Manual (Survey Department of Sri Lanka 2019) and the National Land Use Policy of Sri Lanka (Department of Land Use Policy Planning

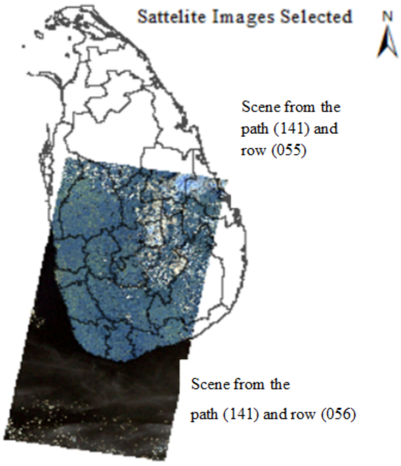

Figure 3: Landsat Images after Layer Stacking

Table 2: Land Cover Classification

Code	Class	Description
1	Water	The land area submerged in water, such as near lakes, rivers, or man-made ponds, dams and the sea.
2	Natural Vegetation	This covers the regions where evergreen trees are primarily found growing wild on the designated territory. Additionally, it encompasses any other region, including mixed forests, grasslands, and scrubs at the river banks.
3	Cultivated Land	Describes areas used for crop cultivation. Crop cultivation including coconut, rubber, tea, cinnamon, palm oil and other economic-level crops. Areas covered with field crops and forage crops.
4	Homesteads	Describes the urban or rural human settlement. Areas containing dwellings, buildings, and small home gardens.
5	Built-up Land	Infrastructures for business, housing, industry, and transportation are all included in these lands. Roads which provide access to the area are also included in this category.
6	Paddy	These are partially flooded lands used for rice cultivation. The paddy lands are identified clearly and differently than other cultivated crop types.
7	Barren Land	These are the lands left with bare soil without any crops, buildings or roads.

2026) were taken into consideration. After conducting a field investigation and gathering local information, the decision was made to focus specifically on analyzing seven land cover classes (Table 2) during the satellite data analysis. Accordingly, signatures were employed to classify several LULC classes, such as built-up, cultivated, and water.

2.4.2 Accuracy assessment of the classified images

Image accuracy was assessed against ground conditions to maintain the quality of the data. A set of random points was generated and tested in a confusion matrix in order to measure the accuracy of both images. By calculating errors of omission and commission, the confusion matrix calculates the degree of agreement and the overall correctness between the reference data and the classified map. The Kappa coefficient, user accuracy, producer accuracy, and overall accuracy are the metrics used to measure accuracy (Rwanga, Ndambuki 2017).

Cohen's Kappa was used for both intra-raster and inter-raster reliability testing. Kappa values range from 0 to +1. Kappa values are interpreted as follows: 0.01-0.20 no agreement, 0.21-0.40 fair agreement, 0.41-0.60 moderate agreement, 0.61-0.80 substantial agreement and 0.81-1.00 perfect agreement (McHugh 2012, Liu, Xia 2010). A value of 1 denotes the perfect agreement between the images.

Table 3: Landscape and Class Level Metrics Calculated

	Index	Description	Unit
i	NP	Number of patches of the corresponding patch type (class), without limit.	number
ii	PD	Number of patches divided by total landscape area and multiplied by 10,000 and 100 (to convert to 100 hectares).	frequency of patches/100 ha
iii	ED	ED equals the sum of the lengths (m) of all edge segments involving the corresponding patch type, divided by the total landscape area (m^2), multiplied by 10,000 (to convert to hectares).	m/ha
iv	AREA_MN	AREA_MN equals the total landscape area (m^2), divided by the total number of patches, divided by 10,000 (to convert to hectares).	ha
v	PAFRAC	Ranges between 1 < PAFRAC < 2. PAFRAC value close to 1 denotes a simple shape for the plaque. PAFRAC values close to 2 indicate complex plaque shapes.	Unitless
vi	SHDI	Shannon's Diversity Index equals minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion. SHDI is used to measure the diversity of the constituents of the landscape. The relative variation in each patch is determined by the SHDI. This index is equal to zero if there is only one patch in the landscape, and it is equal to one if there are more patches and the distribution of the area grows in proportion to the variety of patches.	Unitless

2.4.3 Calculating land fragmentation in the landscape level and class level

FRAGSTATS offers a potent and comprehensive collection of descriptors of the patterns of the land. It is a freely licensed tool developed for quantifying land fragmentation (Chen, Lannone 2020, MacGarigal, Marks 1995). The tool provides a detailed analysis from the patch level, class level to landscape level (Tejaswi 2007). Raster maps are imported into FRAGSTATS, the software to generate a definite special pattern quantification.

FRAGSTATS software, ver. 4.2© was accompanied in this study while the conversion of the images to TIFF format was done using ArcGIS software. Metrics used in the fragmentation study are described in Table 3.

Examples of Fragmented locations are visualized using the Google Earth images and time comparison tool of the Google Earth engine. However, due to the picture quality and availability, comparisons between the same years of the selected locations were not portrayed in the analysis.

3 Analysis

3.1 Accuracy Assessment of Classified Images

Using the equalized stratified random sampling method, 20 random points were generated for each land class in both images (140 points per image was generated), and accuracy was evaluated using Arc GIS and Google Earth pro for the accuracy evaluation.

With an overall accuracy of 84% (Kappa coefficient = 0.82) in 2001 and 85% (Kappa coefficient = 0.80) in 2021, both images demonstrated good classification accuracy. The results of the Confusion Matrix are recapitulated in Table 4.

3.2 Temporal variation of the land proportions in 2001 - 2021

Figures 5 and 6 present the classified images for 2001 and 2021, illustrating the identified land classes. Land proportions of both periods were analyzed together in order to identify the land cover changes over 20 years. Cultivated land denotes the most prevalent land-use type in the area in 2001 as well as 2021. During the study period, the land area covered by natural vegetation showed a significant increase (11.74%) in the study area, while cultivated lands decreased by about 5% within the study period. Figure 7 recapitulates

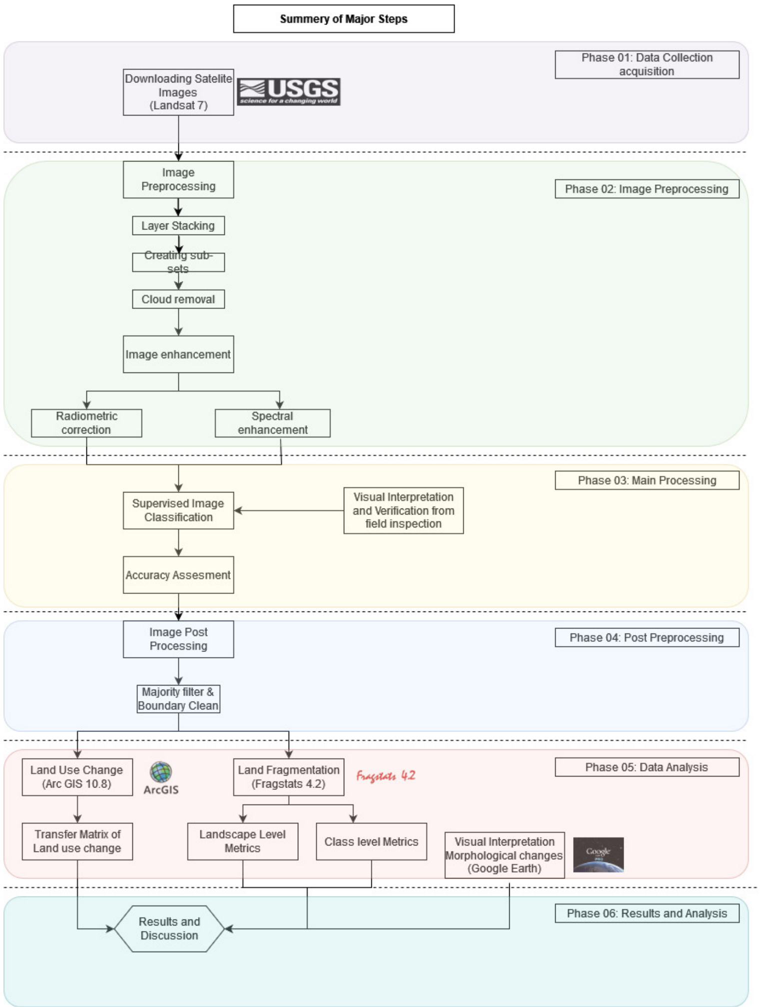

Figure 4: Study design

that paddy land decreased by 7.73% while the homesteads decreased by 6.44%. The proportion of built-up land increased from 1.47% in 2001 to 7.10% in 2021 depicting a growth of 5.63%. Barren land increased from 0.17% to 1.42% while the water has increased only by 0.1% which is not a considerable change.

To further analyze the land cover change, using overlay functions of ArcGIS 10.8 software the traditional area cross-tabulation matrix (transition matrix) was calculated (Table 5). The transfer matrix of land cover within the buffer zone (5 km) of the expressways was developed to study the changing trend of various land cover types in the buffer zone with time. 11,066.14 ha of cultivated land was transformed into natural vegetation, representing the largest conversion. A large area of paddy land was converted into cultivated land (8,530.64 ha) and natural vegetation (7,218.78 ha). The barren land mainly transferred to natural vegetation and built-up lands depict that apart from the barren lands left fallow, which gradually converted to natural vegetation, the purpose of land clearance was mainly for new constructions. The integral change of the area of water is not great.

Switching in and out rates of barren lands were higher than those of other covers. The lowest switching in and switching out were recorded from the areas covered by water.

3.2.1 Analysis of land area variation rate and the dynamic degree

Table 6 illustrates the area variation rate and the dynamic degree of land cover type changes during the period for a broader understanding of the temporal changes in land cover. The land variation rates of built-up land cover (381.71%) and barren lands

Table 4: Accuracy Evaluation of the Land Cover Classifications of 2001 and 2021

	2001		2021	
	PA	UA	PA	UA
Water	100%	95%	100%	100%
Natural Vegetation	77%	85%	94%	85%
Cultivated Land	66%	95%	80%	80%
Homestead	100%	80%	74%	85%
Built-up Land	100%	75%	86%	95%
Paddy	65%	65%	75%	75%
Barren Land	100%	95%	88%	75%
Overall Accuracy	84%		85%	
Kappa coefficient	0.82		0.83	

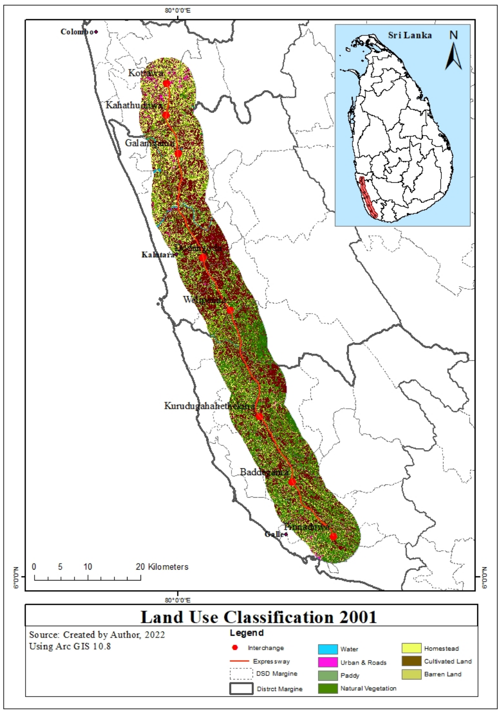

Figure 5: Land Use Classification 2001

(741.39%) were the highest and the variation rate of cultivated land (-12.37%) was the lowest.

Further, the variation direction of land for Natural vegetation, Built-up lands, Barren lands and Water shows positive values displaying a growing trend of the particular land cover. The variations of Paddy, Cultivated Land and Homesteads are negative, demonstrating a declining trend.

3.3 Spatial Variation of Land Cover Change

To analyze land cover changes spatially, 1-5 km buffer zones were demarcated using the buffer analysis tool of ArcGIS 10.8. The 2-way STDP stretch is considered as a single line for the analysis (Figure 8).

Figure 9 depicts the percentage of land covers in each one-kilometer buffer in 2001 and 2021. In 2001, cultivated land occupied most of the land in each buffer. Homesteads were mostly concentrated in the 5th km zone. However, homesteads were declined from each zone by 2021. Land obtained by the Cultivated land was mostly concentrated within the first km zone in 2001.

Considering the percentage of land cover in 2021, the cultivated lands still remain as the dominant land cover type of 1st, 2nd, 3rd km buffer zones. Natural vegetation is

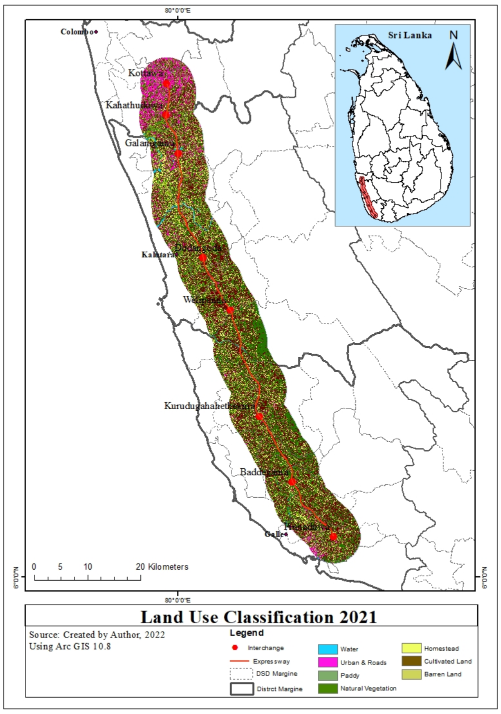

Figure 6: Land Use Classification 2021

dominant in the 5th km zone. The area obtained by the urban and roads in 2001 was less than 2% for each zone. However, the urban lands have increased significantly by 2021 in each zone, while in the 5th km buffer zone depicting 7% of urban growth. Barren lands have obtained more than 1% of each buffer zone and nearly 2% at the 5km buffer. Water bodies spread over less than 1% of each zone.

Comparatively, when considering the amount of change, natural vegetation has increased in all the buffer zones by more than 10%. Barren lands also increased. In contrast to built-up lands and natural vegetation, other land covers such as cultivated lands, homesteads, and paddy lands show a declining trend. The largest decline in cultivated land was recorded in the first km buffer zone (8%) and the smallest decline was recorded in the 5th km buffer zone (2%). Homesteads in all the buffer zones have declined while the most is recorded from the 5th buffer zone (9%). Area change in each zone is depicted in Figure 10.

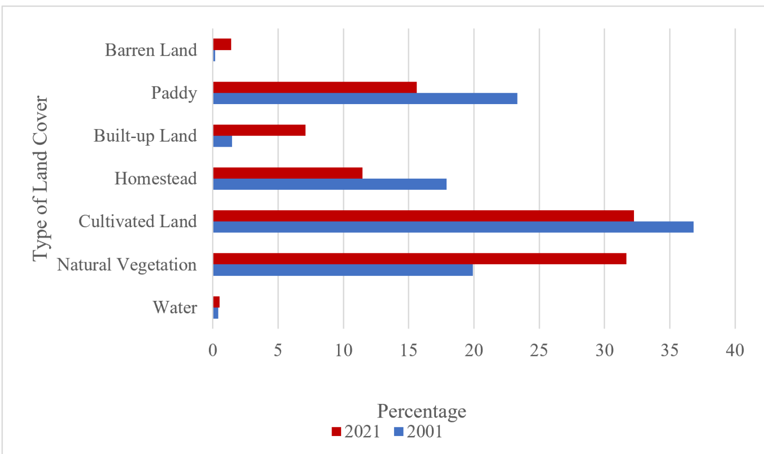

Figure 7: Land Cover Change between 2001 and 2021

Table 5: Transition matrix of Land Use/Cover Types 2001 to 2021 (ha)

	Land Class	2021 Water	Natural Vegetation	Cultivated Land	Homestead	Built-up Land	Paddy	Barren Land	Total	Switching-out rate (%)
2001	Water	338.41	70.11	7.65	3.83	0.44	5.62	0.00	426.06	36.31
	Natural Vege	123.07	9022.80	6031.93	2237.60	427.12	2522.97	106.39	20471.88	72.27
	Cultivated Land	21.64	11066.14	13268.23	4164.51	2504.19	6159.32	645.72	37829.76	59.98
	Homestead	9.66	4896.66	5097.08	2595.19	2882.31	2577.65	327.14	18385.69	77.95
	Built-up Land	22.52	217.62	178.93	90.43	767.41	138.88	97.98	1513.76	89.48
	Paddy	15.94	7218.78	8530.64	2671.13	670.40	4621.15	254.78	23982.84	71.19
	Barren Land	0.06	43.34	37.63	8.20	41.28	16.28	26.60	173.39	98.18
	Total	531.31	32535.46	33152.09	11770.89	7293.14	16041.87	1458.62	102783.38	
	Switching- in rate (%)	20.57	55.93	64.93	85.88	49.30	80.73	99.97	100	

Table 6: Area Variation Rate and the Dynamic Degree of Land Use Type

Land Classification	2001 (ha)	2021 (ha)	Area variation rate %	Dynamic degree %
Water	426.30	531.61	24.70	1.24
Natural Vegetation	20480.47	32549.08	58.93	2.95
Cultivated Land	37843.18	33163.47	-12.37	-0.62
Homestead	18392.06	11774.51	-35.98	-1.80
Built-up lands	1514.90	7297.39	381.71	19.09
Paddy	23989.40	16047.00	-33.11	-1.66
Barren Land	173.43	1459.24	741.39	37.07

3.4 Land Fragmentation

The images were converted into TIFF format using ArcGIS software. Land fragmentation in the study area was calculated using FRAGSTATS, ver. 4.2©. Accordingly, class-level and landscape-level metrics were generated to assess the fragmentation of the land cover types identified in the classification.

Landscape-level metrics have been used to quantify the landscape structure of the study area over time by providing deeper insights to define the landscape changes with time (Table 7). Apart from the percentage of land change, this metric offers insights into the shape and other characteristics of the land change.

Accordingly, the study area increased its number of patches during 2001–2021 from 115769 to 174228. Patch density was increased by 56.8484. Meanwhile, edge density also increased from 285.66 m ha-1 to 364.68m ha-1. The mean patch size of the total landscape has reduced by 0.30. Heterogeneity, which was assessed using the Shannon diversity index, did not change substantially; only a slight increase was recorded from 1.44 to 1.54. PAFRAC value denotes the shape complexity of the landscape. In this scenario, both PAFRAC values are closer to 2 indicating extremely complicated shapes in the landscape from both periods.

Figures 11 and 12 visually illustrate the detrimental impact of the expressway on the connectedness of the paddy fields. The fragmentation of the paddy land resulted in the loss of its cohesive connection to the main field.

Table 7: Metrics at the Landscape Level

	NP	PD (# of Patches/ 100 ha)	ED (m/ha)	AREA_MN (ha)	PAFRAC	SHDI
2001	115769	112.5794	285.6642	0.8883	1.5797	1.4378
2021	174228	169.4278	364.6828	0.5902	1.6269	1.5447

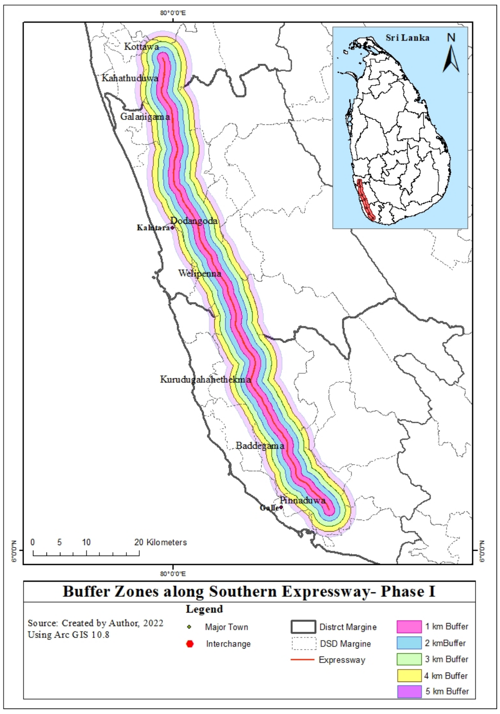

Figure 8: Buffer Zones along Southern Expressway

Class metrics (Table 8), revealed that the paddy patches are shrinking and becoming more fragmented. The total paddy area declined by 8106.4ha and the remaining paddy patches decreased in size (AREA_MN) by an average of close to 0.40 ha. NP and PD metrics reveal that the overall paddy land was shrinking between 2001 and 2021, and also became more fragmented. The number of patches of paddy land increased from 31084 to 43112 within the period of study.

The overall cultivated land depicted a shrinking pattern (4426.1ha), while the NP increased (19576 in 2001 and 32518 in 2021). Increased PD (19.0367 in 2001 and 31.622 in 2021) depicted the fragmented cultivated area. Further, the LPI of the cultivated lands was 6.0003ha in 2001 and became 0.6172ha in 2021, depicting the shrinking habit of the patches in size.

The total area occupied by built-up land was 1,590.3ha in 2001 and 7,166.61ha in 2021, representing an increase of 5,576.31 ha. Patch size (Area_MN) of the built-up lands on average decreased by 0.3639 ha while built-up lands PD increased from 4.5948

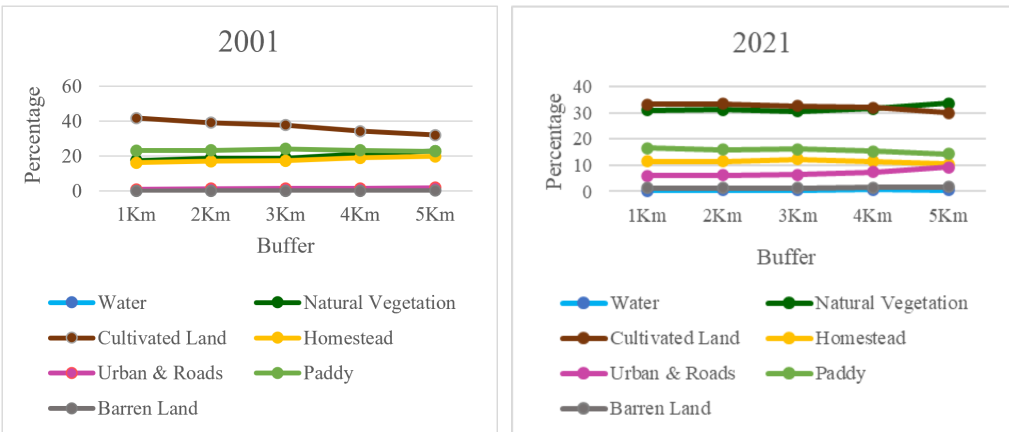

Figure 9: Percentage of Land-Use Types in each Buffer Zone in 2001 and 2021

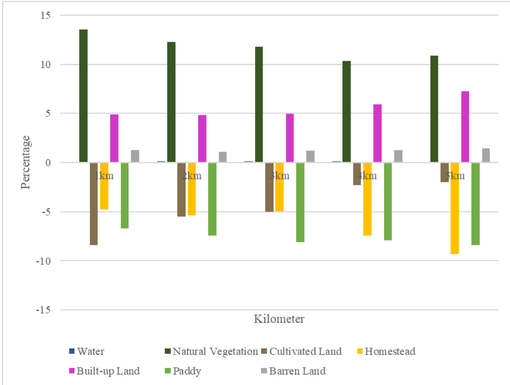

Figure 10: Area Change of Land Cover Types along the Expressway in Every 1 km Buffer Zone

Figure 11: Paddy Land Fragmentation near Kottawa

to 9.9491 in 2021, depicting the growth of small clusters of built-up lands in the study area. The number of patches increased by 5506 and the largest patch index also increased from 0.0319 from 2001 to 1.2082 in 2021, depicting the growth of the built-up patches. These metrics reveal that built-up lands, in contrast with paddy and cultivated lands are becoming larger in size and number.

Even though natural vegetation increased in total area by 12,161.34 ha, the number of patches increased from 26,057 to 41,273. These changes in the number of natural vegetated patches suggest that the natural vegetated lands are becoming more fragmented. PD of the natural vegetation also increased from 25.33 in 2001 to 40.13 in 2021.

On the other hand, these same metrics (PD) reveal that the number of Homesteads became more dispersed between 2001 and 2021 (32.6432 in 2001, 40.0678 in 2021). The number of patches in class level for homesteads (depicted in Table 8) increased (33568 in 2001 and 41203 in 2021) but the total area occupied by the homesteads was reduced by 6641.01ha within the time period.

AREA_MN decreased over time in all land cover types other than natural vegetation and built-up land cover. It describes that both land covers are growing in size while being fragmented. The largest LPI was recorded for cultivated lands in 2001 and followed by the natural vegetated lands. But after 20 years of time, the natural vegetation records the largest patch index, followed by built-up lands.

LPI of the built-up land cover was 0.0319 in 2001 and has increased to 1.2082ha in 2021, depicting the clear growth and spreading its dominance over the area. Barren lands also increased in TA (183.6 in 2001 and 1510.29 in 2021) and the number of patches increased (569 in 2001 and 5597 in 2021). The expansion of the built-up class is visualized using Google Earth images in Figure 13 and Figure 14.

Figure 12: Before and After Images of the Remunagoda Area

Table 8: Metrics Values at the Class Level

	TA		NP		PD		LPI (%)		AREA_MN (ha)	
	2001	2021	2001	2021	2001	2021	2001	2021	2001	2021
Water	428.13	537.3	190	294	0.1848	0.2859	0.192	0.2106	2.2533	1.8276
Natural Vegetation	20484.45	32645.79	26057	41273	25.3391	40.1359	1.3604	2.8618	0.7861	0.791
Cultivated Land	37296.81	32870.7	19576	32518	19.0367	31.6221	6.0003	0.6172	1.9052	1.0108
Homestead	18578.43	11937.42	33568	41203	32.6432	40.0678	0.7329	0.0355	0.5535	0.2897
Built-up Land	1590.3	7166.61	4725	10231	4.5948	9.9491	0.0319	1.2082	0.3366	0.7005
Paddy	24271.47	16165.08	31084	43112	30.2276	41.9242	0.2201	0.1329	0.7808	0.375
Barren Land	183.6	1510.29	569	5597	0.5533	5.4428	0.0049	0.013	0.3227	0.2698

4 Discussion

Road construction and development have become an international concern due to the environmental and socioeconomic impacts generated by them (Zheng et al. 2021). Consistent with the findings in the literature, the results generated by the maps and the FRAGSTATS tool indicate that the STDP first phase has caused significant land use and landscape changes in the surrounding land. Accordingly, the land cover classification and field surveys identified 7 land covers (Water; Natural Vegetation; Cultivated lands; Homesteads; Built-up lands; Paddy and Barren lands). The high dynamic degree of built-up lands (19.09%) and barren land (37.07%) and the negative dynamic degrees of paddy (-1.66%), homestead (-1.80%), and cultivated land (-0.62%) suggest a shift from agriculture-dominated landscapes toward urban and transitional land uses, reflecting the broader processes of urban expansion and land-use restructuring. The observed changes may be attributed to improved accessibility, increased land values, and the emergence of new economic opportunities along the development corridor, which encourage residential, commercial, and speculative land development.

The homesteads of each zone declined, while the change rate varied dynamically. In contrast the built-up land cover has increased dynamically in each buffer zone. This pattern indicates that urban expansion is more pronounced in areas proximate to the expressway, particularly within the 5 km buffer, facilitating the outward growth of nearby town centers such as Pannipitiya, Pitipana, Kesbewa, Olaboduwa, Horana, Wadduwa, Waskaduwa, Nagoda, Uragasmanhandiya, Karandeniya, Thalgampala, and Galle. This finding supports the argument of Zheng et al. (2021) that land cover dynamics along transportation corridors are shaped not only by infrastructure development itself but also by the interaction between natural environmental characteristics and regional development trajectories. Consequently, the heterogeneous patterns observed in the study

Figure 13: Built-up Land Expansion in Kuruduwatta Area

Figure 14: Cultivation Land Fragmentation near Paragasthota Area

area highlight the importance of considering local contextual factors when assessing the landscape impacts of major transportation infrastructure projects.

Isolated or fragmented cultivated lands and isolated paddy patches that were abandoned or became economically less valuable have naturally grown up to the natural vegetated land following the natural succession. Apart from that planting of trees, shrubs and ornamental plants beside the expressway after finishing the constructions to contribute to the aesthetic value of the area has also contributed to the increase of natural vegetation over the area. Although land occupancy increased, the number of patches of natural vegetation increased by 15,216 and patch density increased by 14.79 over the study period.. The findings of Alexander, Waters (2000) suggest that fragmentation of a natural vegetation reduces ecological connectivity between habitats, isolates plant and animal populations, limiting species varieties in the landscape and disrupts the ecological processes. The ability of the ecosystems to support biodiversity and to maintain environmental functions such as soil conservation and water regulation may decline in the long term (Jiayin et al. 2020). Consequently, continued fragmentation of natural vegetation may lead to habitat degradation and increased vulnerability of ecosystems within the landscape.

Bren d'Amour et al. (2016) highlight that, in many countries, urban expansion is expected to reduce the overall share of national croplands. The projections indicate that approximately 1.8% to 2.4% of global cropland will be converted to urban land between 2000 and 2030. In line with this global trend, a substantial extent of cultivated land (2504.19 ha) has been converted into built-up land, demonstrating the growing pressure of urbanization on agricultural landscapes. York et al (2011) noted that the expressways support reducing the amount of cropland, rangeland, and grassland while contributing to the polycentric and riparian patterns in the landscape. Consistent with York et al. (2011), the largest patch index of cultivated land (6.0003% in 2001) declined sharply (0.6172% in 2021), indicating a reduction in patch size alongside an increase in patch density in our study area. Concurrently, the loss of cultivated land may result in significant economic consequences, given that these areas are predominantly occupied by economic crops such as coconut, rubber, cinnamon, oil palm and tea. This fragmentation pattern suggests that the impact of the expressway extends beyond direct land conversion, influencing the spatial organization and continuity of agricultural landscapes and may also affect agricultural productivity, rural livelihoods, and the long-term sustainability of the regional agricultural sector.

The paddy land was also reduced by 8% (8106.4ha), while the number of patches increased by 12028 with increased PD. The security of the food supply and the sustainability of the study area are threatened by the drastic decline of farmlands such as paddy (Makbul et al. 2021), which ends the long history of tillage and the land's supportive roles in the environment (Song et al. 2016). As noted by Herath (2016) fragmentation of paddy lands adversely affects ecological integrity, agricultural productivity, and hydrological connectivity. Smaller and irregular plots reduce mechanization efficiency, increase production costs, and lower yields. Consequently, fragmented lands become economically unviable, leading to land abandonment or conversion to non-agricultural uses. These findings suggest that the impacts of expressway-induced development extend beyond direct land conversions.

A large number of contiguous homesteads and cultivated lands were converted to built-up areas. Built-up lands increased by 6%, mainly due to the upgrading of local roads, which provided access to the expressway. These access roads positively impacted on establishing and upgrading of the local businesses, homesteads and town centers. In addition to acting as conduits for the movement of commodities and services, expressway development encourages urban growth along its paths (Song et al. 2015). Tian, Wu (2015) also report accelerated peri-urban growth following improved accessibility. Barren lands also increased by 1%, while switching in and switching out rates of the barren lands were the highest, depicting that the land clearance and conversion to another land cover were rapid during the period. The lowest switching in and switching out rates were recorded from the water areas.

The study period suggested that the richness of the landscape experienced rapid growth over 20 years. The increase in the indices of ED, NP and PD showed that the landscape in the study area has experienced more fragmentation than integration over time. The number of patches across all land cover types in the study area has increased. Scattered patches in complex shapes are frequently visible after construction of an expressway (Zhao et al. 2021). Although all identified land cover types exhibit some degree of fragmentation, natural vegetation, cultivated lands, and paddy fields are the most affected. In contrast, urban areas are not significantly fragmented; rather, they are expanding across different locations, leading to an increase in the number of urban patches. In this context, the development and operation of expressways can be identified as a key driver of these transformations, as they significantly influence topography, land cover types, and regional landscape patterns (Zhao et al. 2021).

5 Conclusion

The Southern Expressway Development Project (STDP) has induced substantial land cover and landscape change in its surrounding areas over the 2001–2021 period. The findings conclude that the cultivated lands and the paddy lands of the overall area significantly declined, while natural vegetation and built-up lands were mainly increased due to natural succession and development activities. The least fluctuation was observed in the water environments over time. Barren lands exhibited the highest rates of switching in and out, reflecting the greatest spatial variation and annual change, while built-up lands showed the second-highest variability. These patterns highlight the impacts of development activities and ground clearances on land cover dynamics.

Metrics of landscape fragmentation revealed a more fragmented and heterogeneous landscape in the area. Policy makers should assess the viability of introducing agricultural land protection zones, particularly for paddy lands, to limit conversion into residential or commercial built-up areas. Regulating urban expansion and promoting high-value crops, agroforestry, and climate-resilient farming practices to make fragmented cultivated lands economically viable are among the recommendations to minimize the effects of landscape change and fragmentation in the study area. Urban areas are largely cohesive, but they are expanding into new locations, resulting in an increased number of urban patches. Observed patterns represent associations with the expressway development, while recognizing that broader urbanization processes, demographic changes, macroeconomic shifts and policy dynamics may also have influenced the land transformation patterns. Thus, targeted interventions are required to mitigate the long-term impacts of fragmentation on food chains, particularly in paddy lands and other perennial cropping systems.

This study primarily captures structural spatial patterns and does not directly represent ecological functionality, biodiversity outcomes, or socioeconomic impacts. Future research could examine landscape connectivity modelling with ecological impact assessments to provide a more comprehensive understanding of how changes in patch configuration affect habitat continuity, species movement, and overall ecosystem functioning over time. A socio-economic analysis would provide a more comprehensive understanding of how changes in patch configuration affect human well-being, land-use livelihoods, and overall regional development dynamics over time.

Overall, the findings underscore that while fostering economic growth and accessibility, expressways can significantly disrupt land cover, agricultural sustainability, and ecological patterns. The findings of the study offer a quantitative assessment of the impacts of the STDP on land use and land cover change. In addition, it demonstrates a GIS- and remote sensing-based methodological approach that can be effectively applied by urban and regional planners to assess land use change patterns and landscape fragmentation in any large-scale change detection study.

References

Alexander S, Waters N (2000) The effects of highway transportation corridors on wildlife: A case study of Banff National Park. *Transportation Research Part C: Emerging Technologies* 8: 307–320. CrossRef

Amarasinghe S (2011) Managing the socio-economic impacts due to compaction operations during construction of Southern Expressway. Master thesis, The University of Moratuwa, Sri Lanka. Available at: https://dl.lib.uom.lk/items/496e1ada-06c5-4c72-8039-47b9fe0c1473/full

Asian Development Bank (2007) Environmental assessment report: Supplementary financing and technical assistance grant. Retrieved from: https://www.adb.org/sites/-default/files/project-document/66236/26522-sri

Bren d'Amour C, Reitsma F, Baiocchi G, Barthel S, Güneralp B, Erb K, Haberl H, Creutzig F, Seto K (2016) Future urban land expansion and implications for global croplands. *Proceedings of the National Academy of Sciences* 114: 8939–8944. CrossRef

Chen B, Lannone B (2020) FRAGSTATS: A free tool for quantifying and evaluating spatial patterns. IFAS extension, FOR362/FR431, 6/2020, University of Florida, Gainesville, FL. CrossRef

Department of Land Use Policy Planning (2026) National land use policy of Sri Lanka. Retrieved from: https://luppd.gov.lk/images/content_image/downloads/pdf/-national_land_use_policy.pdf, Battaramulla

Department of Meteorology (2025) Climate of Sri Lanka. Department of Meteorology, Sri Lanka. Retrieved from: http://www.meteo.gov.lk/index.php?option=com_content&-view=article&id=94

Feng S, Liu S, Jing L, Zhu Y, Yan W, Jiang B, Liu M, Lu W, Ning Y, Wang Z, Li Q, Jia J (2021) Quantification of the environmental impacts of highway construction using remote sensing approach. *Remote Sensing* 13: 1–19. CrossRef

Gomes P, Dabare L (2018) Impact of Southern Expressway on land prices. Advances in civil and environmental engineering practices for sustainable development. In: *Proceedings of the 6th International Symposium of the University of Ruhuna, Sri Lanka*, 151–156

Gunasekera A, Weerakoon K (2020) Impact of interchanges on land use conversions and land value variations in the Southern Expressway; Sri Lanka. International Conference on Real Estate Management and Valuation. Retrieved from: https://journals.sjp.ac.lk/index.php/icremv/article/view/4955/3753

Herath H (2016) Causes and effects of paddy land filling in Western Province research report. Hector Kobbekaduwa Agrarian Research and Training Institute, Sri Lanka. Retrieved from: http://viduketha.nsf.gov.lk:8585/slsipr/24681/24681-FULL%20TEXT.pdf

Jayasinghe A (2013) A study of the urbanizing pattern in Kegalle district, Sri Lanka with connectivity analysis. *International Journal of Scientific Knowledge* 2: 7–19

Jia X, Liu F, Wang D (2019) Prediction of vegetation cover index along highways in high-altitude areas using machine learning. *Applied Ecology and Environmental Research* 17: 12551–12571. CrossRef

Jiayin G, Mingfei Z, Zhaoguang H, Wei S (2020) Influence of expressway construction on the ecological environment and the corresponding treatment measures: A case study of Changyu (Changchun- Fuyu Lalin River) expressway, China. *Nature Environment and Pollution Technology* 19;3: 195–1201. CrossRef

Karunathilaka H, Devapriya K, Shanika V (2021) Effect of social and environmental factors on expressway construction in Sri Lanka. In: Sandanayake Y, Gunatilake S, Waidyasekara K (eds), *Proceedings of the 9th World Construction Symposium, Sri Lanka*. 280–289. CrossRef

Kumari M, Priyadarshana P, Weerasekera K (2015) Future impact of current toll-gates on the capacity of the Southern Expressway. *OUSL* Journal,9: 19–40. CrossRef

Liu D, Xia F (2010) Assessing object-based classification: Advantages and limitations. *Remote Sensing Letters* 1: 187–194. CrossRef

Liu Y, Cao X, Li T (2020) Influence of accessibility on land use and landscape pattern based on mapping knowledge domains: Review and implications. *Journal of Advanced Transportation* 2020: 1–12. CrossRef

Lu D, Yu H, Yu G (2014) Assessing the land use change and ecological security based on RS and GIS: A case study of Pingdingshan City, China. *Advanced Materials Research* 905: 329–333. CrossRef

MacGarigal K, Marks B (1995) FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure. U.S. Department of Agriculture, Forest Service; Retrieved from https://www.fs.usda.gov/research/treesearch/3064

Makbul Y, Limnakrisna N, Wijaya N, Ratnaningtyas S, Dwiyantoro P, Cokrowitianto A (2021) The effect of toll road development on agricultural land conversion in Indonesia: An empirical analysis. *International Journal of Modern Agriculture* 10: 880–890

McHugh M (2012) Interrater reliability: The Kappa statistic. *Biochemia medica* 22: 276–282. CrossRef

National Research Council (2001) Grand challenges in the environmental sciences. National Academies Press, Washington DC. Retrieved from: https://nap.nationalacademies.org/read/9975/chapter/1

Oumer H (2009) Land use and land cover change, drivers and its impact: A comparative study from Kuhar Michael and Lenche Dima of Blue Nile and Awash Basins of Ethiopia. Master's Thesis, Cornell University, New York. Retrieved from https://-core.ac.uk/download/pdf/132684799.pdf

Pallag O (2000) *The effect of linear infrastructures on habitat fragmentation. Hungarian State of the Art Report.* Technical and Information Services on National Roads, Budapest

Prakasam C (2010) Land use and land cover change detection through remote sensing approach: A case study of Kodaikanal Taluk, Tamil Nadu. *International Journal of Geomatics and Geosciences* 1: 150–158

Road Development Authority (2014) Initial environmental examination: SRI: Integrated road investment program – Project I (Southern Province). Road Development Authority, Ministry of Highways, Ports and Shipping, Government of Sri Lanka for the Asian Development Bank. Retrieved from: https://www.adb.org/sites/default/files/project-documents//47273-002-iee-01.pdf

Rwanga S, Ndambuki J (2017) Accuracy assessment of land use/land cover classification using Remote Sensing and GIS. *International Journal of Geosciences* 8: 611–622. CrossRef

Sarojini P (2014) Socio-economic implications on southern highway project special reference to evicted people. International research conference articles of Kotelawala Defense University. Retrieved from: http://ir.kdu.ac.lk/handle/345/1625

Shiromani A, Waidyasekara K, Wijerathna M (2025) Mitigating the impacts of expressway construction on wildlife. *Sustainable Futures* 10: 101432. CrossRef

Song J, Cai D, Deng J, Wang K, Shen Z (2015) Dynamics of paddy field patterns in response to urbanization: A case study of the Hang-Jia-Hu Plain. *Sustainability* 7: 13813–13835. CrossRef

Song J, Ye J, Zhu E, Deng J, Wang K (2016) Analyzing the impact of highways associated with farmland loss under rapid urbanization. *ISPRS International Journal of Geo-Information* 5: 94. CrossRef

Southworth J, Marsik M, Qiu Y, Perz S, Cumming G, Stevens F, Rocha K, Duchelle A, Barnes G (2011) Roads as drivers of change: Trajectories across the tri-national frontier in MAP, the Southwestern Amazon. *Remote Sensing* 3: 1047–1066. CrossRef

Suresh T (2018) Study on effectiveness of strategies to reestablish landscape connectivity of Southern expressway. Bachelor's dissertation. The University of Moratuwa, Sri Lanka

Survey Department of Sri Lanka (2019) Mapping manual. Retrieved from: https://-www.survey.gov.lk/sdweb/pdf/download/publications/Mapping_Manual.pdf

Tejaswi G (2007) Manual on deforestation, degradation, and fragmentation using Remote Sensing and GIS. MAR-SFM Working Paper 5 / 2007, Forestry Department: Food and Agriculture Organization of the United Nations. https://www.fao.org/3/ap163e/-ap163e.pdf

Tian G, Wu J (2015) Comparing urbanization patterns in Guangzhou of China and Phoenix of the USA: The influences of roads and rivers. *Ecological Indicators* 51: 23–30. CrossRef

Turner B, Lambin E, Reenberg A (2008) The emergence of land change science for global environmental change and sustainability. *Proceedings of the National Academy of Science of the United States of America* 104: 20666– 20671. CrossRef

Wu C, Lin Y, Chiang L, Huang T (2014) Assessing highway's impacts on landscape patterns and ecosystem services: A case study in Puli Township, Taiwan. *Landscape and Urban Planning* 128: 60–71. CrossRef

York AM, Shrestha M, Boone CG, Zhang S, Harrington JA, Prebyl TJ, Swann A, Agar M, Antolin MF, Nolen B, Wright JB, Skaggs R (2011) Land fragmentation under rapid urbanization: A cross-site analysis of Southwestern cities. *Urban Ecosystems* 14: 429–455. CrossRef

Zhan J, Chen Y, Yang Y, Wang W (2026) Effects of highway construction on landscape patterns, ecosystem service value, habitat connectivity and their associations in Zhejiang, China. *Forests* 17: 338. CrossRef

Zhao L, Fan X, Lin H, Hong T, Hong W (2021) Impact of expressways on land use changes, landscape patterns, and ecosystem services value in Nanping City, China. *Polish Journal of Environmental Studies* 30: 2935–2946. CrossRef

Zhao Q, Wen Z, Chen S, Ding S, Zhang M (2020) Quantifying land use/land cover and landscape pattern changes and impacts on ecosystem services. *International Journal of Environmental Research and Public Health* 17: 126. CrossRef

Zheng F, Huang J, Feng Z, Xiao C (2021) Impact of the Kunming–Bangkok highway on land use changes along the route between Laos and Thailand. *Land* 10: 991. CrossRef