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The Comprehensive Analysis of the Land-Use Land Cover Changes in the Gal-Oya Watershed

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Abstract

Due to human and environmental interaction, Land Use and Land Cover are changing drastically. This study presents a comprehensive analysis of land-use and land-cover (LULC) changes in the Gal-Oya watershed, aiming to understand the spatial and temporal transformations over the past three decades. Using satellite imagery from 2005, 2015, and 2025, the study applied unsupervised classification techniques within a GIS framework to map and quantify changes across key land-cover categories, including forest, agriculture, built-up areas, and water bodies. Accuracy assessments and change detection analyses were conducted to ensure the reliability of the results. The results show that there are remarkable changes in all the land cover throughout the years. Paddy fields cover 565.63 ha of land; meanwhile, 96.07 ha of land were built on in 2005. The greatest and smallest changes in land cover were observed as 395.44 hectares and 142.52 hectares, respectively. However, in the current year 2025, 27.30% of areas cover 658.40 ha of dense forests, and 142.52 ha represent built-up areas, with 5.91% recorded as the highest and the least LULC changes, respectively. Barren lands changed into forest covers and scrublands, while cultivation areas were converted into scrublands and built-up areas. Other land use classes were also converted to other types in the Gal Oya region. Due to increasing population pressure, inadequate land management systems, and limited irrigation development, these changes have led to several ecological impacts and consequences in the study area. The findings of this study underscore the urgent need for a thorough evaluation of human activities within the Gal-Oya watershed and the implementation of sustainable land-use and land-cover practices, including closely monitoring and restoring bare lands, conserving forest and scrubland ecosystems, rehabilitating degraded and impoverished areas to create viable grazing lands, and curbing the unchecked expansion of cultivated zones. Such measures are crucial for mitigating environmental degradation and fostering long-term ecological resilience in the region.

Keywords

Gal Oya, Land-Use-Land-Cover (LULC), Land Management, Watershed Management Strategies & Ecological Resilience

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INTRODUCTION

Lambin et al. (2003) observed that land-use change is driven by synergistic combinations of factors, including resource scarcity which increases production pressure on natural resources shifting market opportunities, external policy interventions, loss of adaptive capacity, and transformations in social organization and attitudes. Lambin et al. (2001) stated that the Gal Oya Watershed is a crucial hydrological system in Sri Lanka that plays a significant role in the region's environmental, economic, and social landscapes. According to Foley (2005), Global croplands, pastures, plantations, and urban areas have expanded in recent decades, accompanied by large increases in energy, water, and fertilizer consumption, along with considerable losses of biodiversity. Globalization and the development of technology cause increased human needs, impacting land use and cover change (LUCC), particularly in watershed areas (Arifasihati & Kaswanto, 2016). Effective watershed management and sustainable development require an understanding of land use changes;

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thus, a watershed develops diverse ecosystems, cultivation and various settlements. The Gal-Oya is a river draining through eastern Sri Lanka, and the river basin covers an area of 1873 km^2 (Withanage et al. 2015). In the Gal Oya irrigation scheme in southeastern Sri Lanka, a system of farmer organization was established in the early 1980s that greatly improved the efficiency and extension of irrigated rice production (Uphoff & Wijayaratna, 2000).

The watershed has anticipated notable changes in land use over the years. Complex socio-economic, environmental and various policies drove them, leading to notable impacts in the watersheds as well. Mapping and quantifying the status of Land use/Land cover (LULC) changes and drivers of change are important for identifying vulnerable areas for change and designing sustainable ecosystem services (Abebe, 2021). Watersheds have been experiencing monumental shifts in land use, considering socio-economic, environmental pressures and policy decisions. These adverse land-use transformations have led the consequences in the study area, it has been far-reaching in ecological and livelihood issues, and long-term sustainability. It is essential for gaining a better understanding of these lad use dynamics. Thus, strategies can be developed to mitigate the negative consequences in the study region and foster a balanced land management approach to safeguard both the community and ecological well-being and resilience, respectively.

Uphoff and Wijayaratna in 2000 noted that, in the Gal Oya irrigation scheme in southeastern Sri Lanka, a system of farmer organization was established in the early 1980s that greatly improved the efficiency and extension of irrigated rice production. The region was initially characterized by various land uses, for instance, various types of vegetation such as forests, dense forests and other ecosystems. However, after the continuous conversion of landscapes, the forest covers were converted into settlements, built-up areas and agricultural lands. Moreover, infrastructure such as roads and irrigation schemes has led the region to be fragmented.

After the introduction of the Gal Oya Development Project, it marked a significant milestone in the mid-20th century. Water stealing, by siphoning or diversion, had become rampant in Gal Oya before our program started (Uphoff & Wijayaratna, 2000). This project focused on improving the sustainable agricultural productivity and thorough regional development through irrigation. Thus, this phenomenon also led the region to increase pressure on water resources and land. Therefore, this comprehensive study focused entirely on examining the contemporary land-use patterns and land use changes in the Gal-Oya watershed over three decades from 2005 to 2025.

MATERIALS AND METHODS

Description of the study area

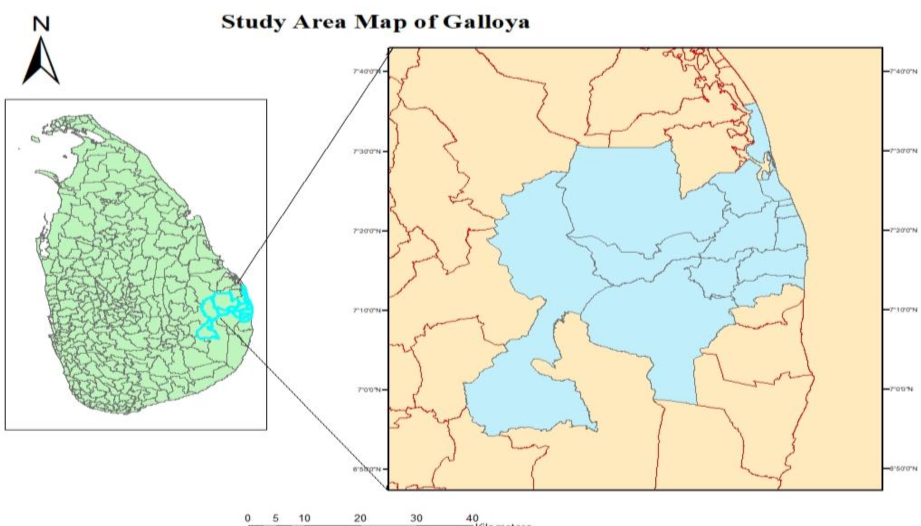

Figure 1: Study Area Map of Gal Oya

It rises in the hill country east of Badulla, flows towards the east coast of Sri Lanka and joins to the Indian Ocean 16 km south of Kalmunai

The Gal Oya Watershed has been recognized as one of the notable water bodies in the southeast dry zone of Sri Lanka. Most research in various fields, including irrigation and management, hydrology, agriculture, and local community participation, has focused on the Gal Oya watershed. It rises in the hill country east of Badulla, flows towards the east coast of Sri Lanka and joins the Indian Ocean 16 km south of Kalmunai (Withanage et al., 2015). In the Gal Oya irrigation scheme in southeastern Sri Lanka, a system of farmer organization was established in the early 1980s that greatly improved the efficiency and extension of irrigated rice production (Uphoff & Wijayaratna, 2000). According to Banu (2021), Senanayake Samudra is currently known as Galoya reservoir, and it is exceptional compared with other reservoirs in Sri Lanka in multiple etiquettes. Ampara district is one of the attractive places for all the economic and regional sectors, especially its coastal belt (Banu, 2024). Irrigation water is provided for 120000 cultivated lands by way of left, and proper forms left canal way, and proper canal way is 32 miles in size and 22 miles in length, respectively (Banu, 2021).

METHODOLOGY

Data Used

Geographic Information System (GIS) techniques were employed to assess the satellite imagery acquired from the United States Geological Survey (USGS) spanning the years 2005 to 2025. Landsat Collection 2 Level 1 images from 2005, 2015, and 2025 were chosen to assess LULC Changes in the study area, along with high-quality data with less than 20% of cloud cover to ensure minimal interference for the analysis.

Enhanced Thematic Mapper Plus (ETM+) for Landsat 7 and Landsat 8 Operational Land Imager / Thermal Infrared Sensor (OLI/TIRS) were examined in the study. To identify vegetation, the OLI bands played a major role, while the TIRS bands offered valuable information on land and water bodies. These datasets comprise Bands from one to seven with a 30-meter resolution. These bands, available in greyscale format, captured the intensity levels of the study area across specific wavelengths and were used to generate the LULC map. All downloaded data were in GeoTIFF format. Table 1 presents the spectral characteristics of the Landsat datasets.

Image Pre-Processing and Classification

The study area was classified into three distinct categories. The table 1 includes a thorough description of the types of data used for the study. In image categorization, these images were allocated to pixels. Unsupervised classification was employed after identifying Areas of Interest (AOI) and naming the information classes, and the area was chosen based on a combination of three band numbers that indicate the nature of the class.

Table 1: Image Pre-Processing and Classification

Year	Date of Acquisition	Types of data	Spatial resolution	Output format
2005	21st of May	Landsat 5 ETM	30m	TIFF
2015	26th of June	Landsat 8 OLI	30m	TIFF
2025	21st of June	Landsat 8 OLI	30m	TIFF

Multiple bands of satellite pictures were combined to build the databases. Google Earth Pro was used to link and synchronize the Landsat subset image with the satellite image of the area of interest. Different band combinations were used to determine the colour of a given class. Table 2 describes the feature description used for the study while the band combination 4-3-2 was utilized in the buildup area, forest, cultivation, scrublands, home gardens, bare lands, and bare paddy fields. Data sets were generated based on the pixel colour.

Table 2: Classes and Description

No	Classes name	Description of Feature Classes
1	Water body	Water areas include rivers, reservoirs, Ponds, lakes, and streams.
2	Home garden	All the vegetation types found in forests, damaged forests, marshlands, mangrove, grassland, and agroforests.
3	Scrublands	
4	Dense forest	
5	Cultivation	Plantation, irrigated agriculture, lowland agriculture, rain-fed agriculture, and declining agriculture.
6	Bare paddy fields	All the bare land, such as without vegetation, uncultivated, rocky terrain, and sandy beaches near rivers and streams.
7	Buildup area	Concrete land surfaces, such as low, medium and high-density roads, residential, commercial and industrial buildings, educational establishments, public transport systems, open-roof concrete buildings and other man-made buildings.

Accuracy Assessment

Accuracy is the measure of the agreement between a standard assumed to be a correct and classified image of unknown quality (Gunathilaka & Fernando, 2022). Additionally, the primary criteria for choosing pixels for the accuracy assessment were easily identifiable places on Google Earth and the high-resolution Landsat image. A total of 70 points (locations) were created in the categorised image of the research area. After creating the classified pictures, the accuracy of the classified images was assessed using ArcGIS 10.8, and the reference column of the accuracy evaluation cell table was filled in using the best estimate for each reference point. Following the classification of the images, assessing the classification accuracy is a crucial next step. The producer's accuracy describes the quantity of commission errors. When pixels from one class are used in other classes, omission mistakes for each class arise. The correctness of the user is another metric that describes the omission errors. ArcGIS 10.8 was used to evaluate the accuracy of the 2005, 2015, and 2025 LULC maps.

The accuracy assessment is a crucial last stage in the categorization process. Finding out quantitatively how well the pixels were sampled into the appropriate land cover groups is its goal. Additionally, the pixel selection for the accuracy assessment focused on easily visible areas on both Google Earth and the high-resolution Landsat picture. The research area's categorized image contained a total of 70 points, or locations. The chosen points were additionally categorised using Google Earth Pro as a reference.

RESULTS AND DISCUSSION

Land Use and Land Cover in 2005

Figure 02 depicts the LULC map of Gal Oya produced using Landsat 8 data. The table 3 presents the land types for 2005, as well as their data. According to the data, the largest category was paddy fields (565.63 ha, 23.45 %), followed by dense forest (495.85 ha, 20.56 %). Other land use categories: waterbody (128.95 ha, 5.35 %), home garden and scrublands (463.22 ha, 19.20%), buildup area (96.07 ha, 3.98 %), and cultivation (370.38 ha, 15.36 %) were also present.

Land Use and Land Cover in 2015

The LULC of Gal Oya 2015 is illustrated in Figure 3. Here, the largest coverage was dense forest with 670.76 ha, 27.81%; meanwhile, waterbody covered 156.32 ha, 6.48% in the least coverage. Cultivation accounted for 317.80 ha, 13.18% of the study area. It was followed by paddy field, which covered a total of 370.54 ha, or approximately 15.36%, scrubland (466.27 ha, 19.33%), barren land (321.97 ha, 13.35%), and build-up area made up 108.28 ha (4.49%), (refer table 3).

Land Use and Land Cover in 2025

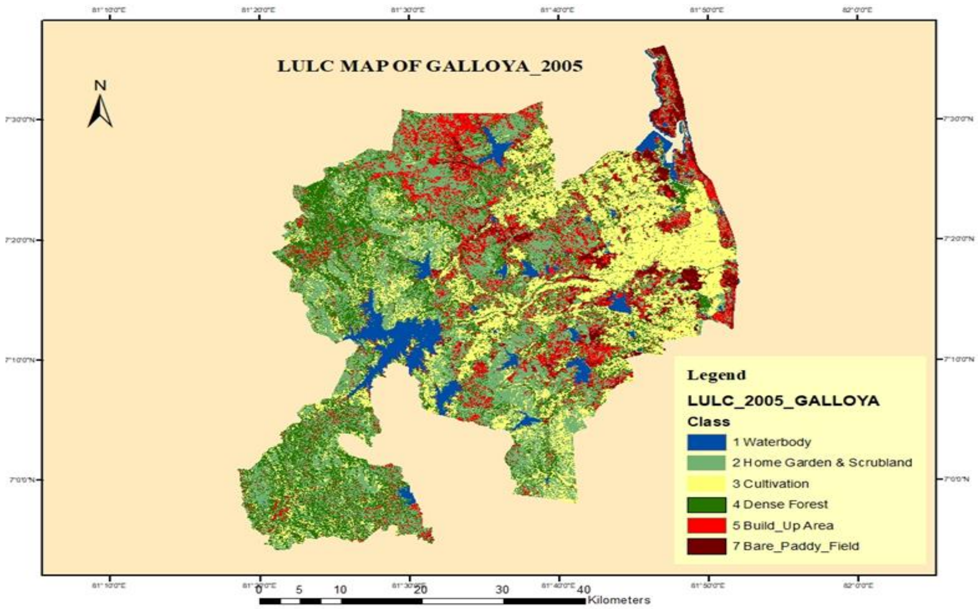

Figure 2: Map of Land Use and Land Cover in 2005

For 2025, the spatial distribution of the LULC Change is shown in Figure 4. The results show that the dense forest takes the first position, occupying 658.40 ha or approximately 27.30% of the total area. In the second position, scrubland occupies 450.07 ha or 18.66 % of the study area. Barren land (440.22 ha, 18.25%) and paddy field (395.44 ha, 16.40%) occupy third and fourth position compared to the total area, respectively. Cultivation maintains the fifth position with 176.03 ha, making up for 7.30%. waterbody is in sixth place in total area with 149.18 ha, representing 6.19%. The buildup area is in the last position with 142.52 ha, meaning 5.91%. Table 3 represents the total area coverage and Land Use and land cover changes over three decades (2005, 2015, and 2025).

Table 3: total area coverage and Land Use and land cover changes over three decades (2005, 2015, and 2025)

LULC Categories	2005		2015		2025	
	(ha)	(%)	(ha)	(%)	(ha)	(%)
Waterbody	128.95	5.35	156.32	6.48	149.18	6.19
Caltivation	370.38	15.36	317.80	13.18	176.03	7.30
Paddy Field	565.63	23.45	370.54	15.36	395.44	16.40
Dense Forest	495.85	20.56	670.76	27.81	658.40	27.30
Scrubland	463.22	19.20	466.27	19.33	450.07	18.66
Barren Land	291.92	12.10	321.97	13.35	440.22	18.25
Build_up Area	96.07	3.98	108.28	4.49	142.52	5.91

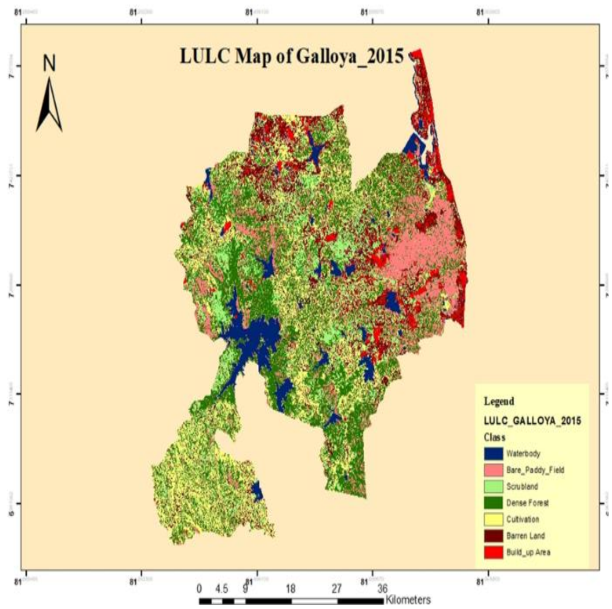

Figure 3: Land Use and Land Cover Map in 2015

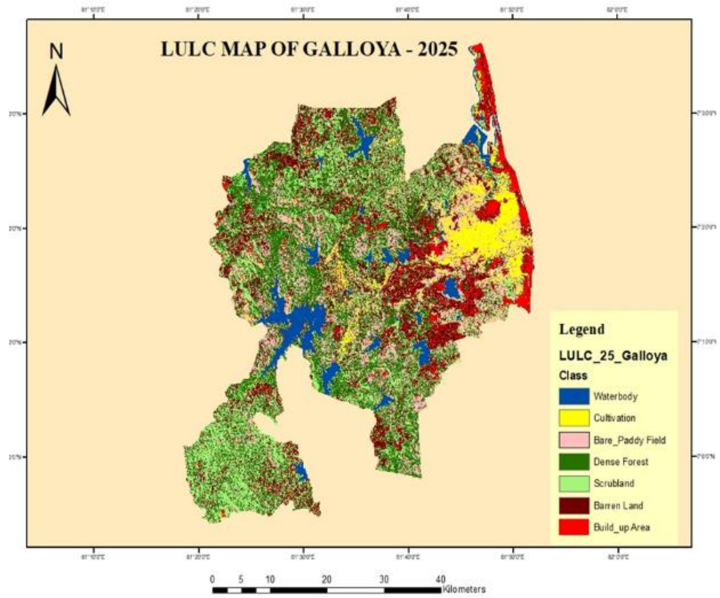

Figure 4: Land Use and Land Cover Map in 2025

Land Use Land Cover Change Detection

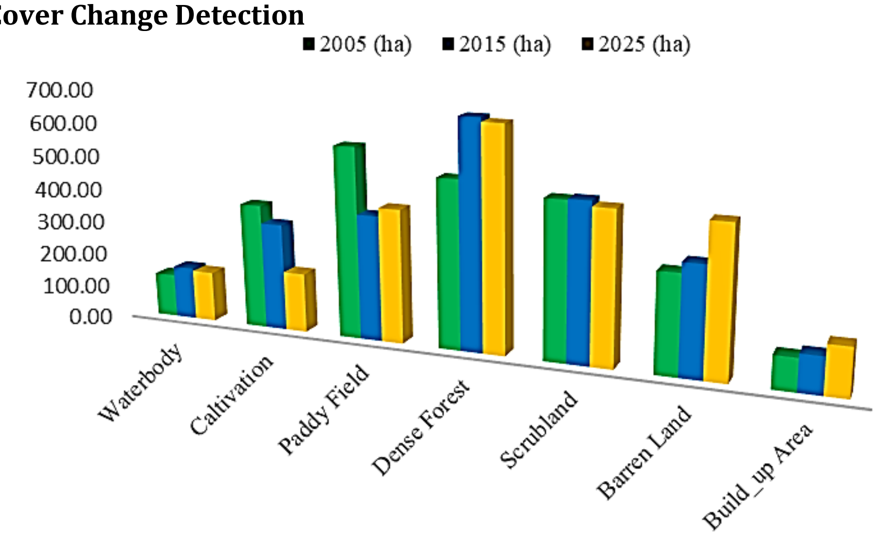

Figure 3: Land Use Land Cover Change Detection

Table 4: Land Use Land Cover Change Detection

LULC Categories	2005 (%)	2015 (%)	LULC Change 2005-2015	2015 (%)	2025 (%)	LULC Change 2015-2025
Waterbody	5.35	6.48	**1.13**	6.48	6.19	**-0.30**
Caltivation	15.36	13.18	**-2.18**	13.18	7.30	**-5.88**
Paddy Field	23.45	15.36	**-8.09**	15.36	16.40	**1.03**
Dense Forest	20.56	27.81	**7.25**	27.81	27.30	**-0.51**
Scrubland	19.20	19.33	**0.13**	19.33	18.66	**-0.67**
Barren Land	12.10	13.35	**1.25**	13.35	18.25	**4.90**
Build_up Area	3.98	4.49	**0.51**	4.49	5.91	**1.42**

Change detection identifies alterations over time and aids resource management. The combination of satellite data and GIS allows for interpretation, with post-classification comparison being a widely used method (Karale et al., 2024; Haque & Basak, 2017). Identifying which LULC type has changed is crucial for change detection. The change detection process is the method of identifying changes in an object or phenomenon by monitoring it at various intervals (Chughtai et al., 2021; Diallo et al., 2022). The changes and transformations in LULC illustrate both the direction of land cover changes and the remaining stable features in the study area period. Albeit, each time interval is roughly examined to detect the origin and destination of changes here in the table 4 and figure 5. Thus, there was a notable shift in the paddy lands between 2005 and 2015. 23.45% of the land was altered, and 15.35%, the deduction rate was -8.09%. Meanwhile, there is a gradual increase of 1.03% from 16.40% in 2025. Dense forest took the second place with 20.56% in 2005 and 27.81%, thus the change was 7.25%. This was reduced by 0.51% of forest lands in 2025. 15.36% of the cultivation area in 2005 was reduced by 2.18% (13.18%) in 2015, and on the other hand, it was reduced by 7.30% in 2025.

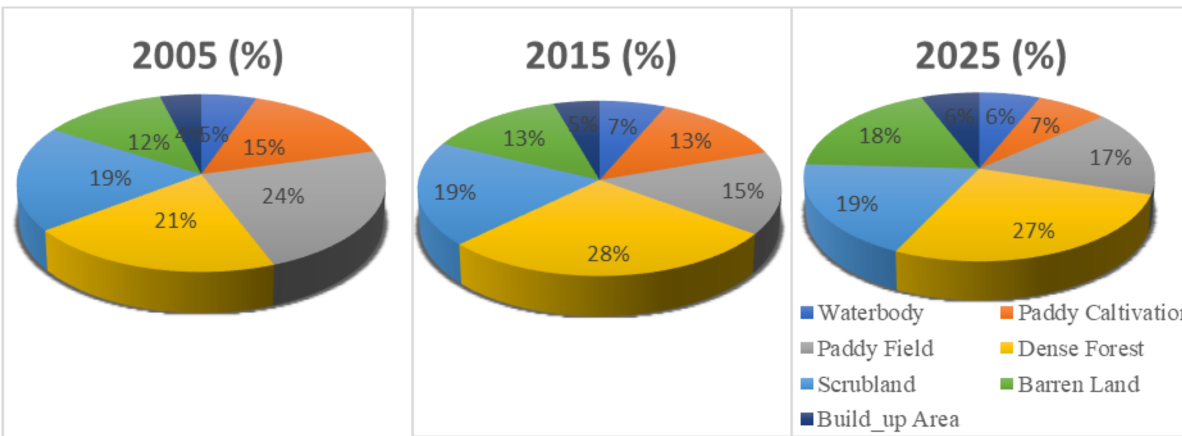

Figure 5: LULC Change Variation in Percentage

In contrast, there is only an increase in barren lands, 12.10% of them were transformed as 13.35% in 2015 and 18.25% in 2025. 1.13% of the waterbody increased from 2005 to 2015; however, a little change occurred in 2015. These things are denoted in Figure 6 also. Most of the bare lands, wetlands, and cultivated areas were also converted into built-up areas throughout the decades. For instance, the land area increased from 3.98% to 4.49% between 2005 and 2015, and then further to 5.91% by 2025. The conversion of scrublands reached about 19.20% to 19.33% from 2005 to 2015. Those areas were occupied by barren lands, cultivation and some built-up areas throughout the years, thus it reduced to 18.66 in the middle of 2025.

LULC Conversion Metrix of Gal Oya - 2005

Table 5: LULC conversion matrix of Gal Oya - 2005

2005	Waterbody	Home Garden	Cultivation	Dense Forest	Scrub	Buil_up Area	Bare_Paddy_Field

User Accuracy	1	0	0.4	0.5	0.6	0.1	0.4
Producer Accuracy	0.83	0.00	0.50	0.63	0.27	1.00	0.4
Error Ommision	16.7	100	50	37.5	72.7	100	60
Error Commission	100	0	40	50	60	10	20
Overall Accuracy	40%						
Keppa Co-Efficient	0.3						

Table 6: LULC conversion matrix of Gal Oya - 2015

2015	**Waterbody**	**Barren Land**	**Cultivation**	**Dense Forest**	**Scrub**	**Buil_up Area**	**Bare_Paddy_ Field**
User Accuracy	0.6	0.4	0.2	0.5	0.6	0.4	0.3
Producer Accuracy	0.6	0.5	0.2	0.5	0.6	0.6	0.3
Error Ommision	37.5	50	81.8	53.3	44.4	42.9	75
Error Commission	37.5	55.6	80	53.3	44.4	55.6	70
Overall Accuracy	40%						
Keppa Co-Efficient	0.3						

Table 7: LULC conversion matrix of Gal Oya - 2025

2025	**Waterbody**	**Caltivation**	**Bare_Paddy Field**	**Dense Forest**	**Scrubland**	**Barren Land**	**Build_up Area**
User Accuracy	0.6	0.4	0.3	0.6	0.6	0.5	0.3
Producer Accuracy	0.8	0.3	0.3	0.6	0.7	1.0	0.0
Error Ommision	16.7	71.4	70	40	30	58.3	33.3
Error Commission	37.5	60	66.7	40	22.2	50	66.7
Overall Accuracy	50%						
Keppa Co-Efficient	0.3						

A classification error matrix is typically formed in evaluating classification errors (Gunathilaka & Fernando, 2022). Thus, tables 5, 6 & 7 mention the matrix of error for each decade. In that way, the overall accuracy for 2005, 2015 & 2025 is 40%, 40%, and 50%, respectively. The Kappa coefficient indicates strong agreement and reasonable accuracy in detecting LULC alterations; thus, all years (2005, 2015 & 2025) have an equal rate of 0.3% in the study. Omissions and commissions of errors are also described in detail in the above tables. However, most areas of the waterbody are changed into scrubland and forest in the respective decades. 2005 had 370.38 ha of cultivation lands, although this has been changed to 176.03 ha in 2025, which is fully converted to forest and scrub lands. A total of 15.36% of the cultivation land cover had reduced by half of percentage. Dense forest dominated by cultivation in 2005, again in 2025, it had changed to scrubland. Barren lands are mostly covered with scrublands. Buildup of land converted into barren lands.

CONCLUSION

The observed changes in land use and land cover (LULC) are primarily driven by population growth and the resulting increased demand for natural resources, including the expansion of agricultural and residential areas in Gal Oya. The study aimed to examine LULC between 2005 and 2025 through GIS techniques and RS data. The findings revealed that there is a significant transformation in all the features, marked by an increase in all feature classes in the study area, *Gal Oya.* Due to the weather fluctuation and temperature increase in the study area, most of the cultivation areas were reduced to various other land uses, such as build-up areas and forest cover. The vegetation cover changed as a split of cultivations and scrublands; however, the cultivation areas were changed to barren lands in 2015. Accordingly, there is an increase in waterbodies compared with 2005 and 2015; however, this was drastically reduced in 2025. The dense forest had increased from 2005 to 2015 by 7.25%, and this was reduced in 2025 by 0.51%. Some of the hilly areas are also in the study area; thus, these areas are fully covered with forests and scrublands. Likewise, barren lands have an increase. For instance, 12.10 ha of land were increased to 18.25 ha over the decades. Meanwhile buildup areas have the same increasing process. For instance, 4.49 ha of buildup area improved by 5.91%. thus, this indicated the proper land use changes and resource reductions in the respective years.

However, there is a risk of a decline in the extent of cultivated land soon. Therefore, the findings of this study highlight the need for a comprehensive assessment of human activities in the study area and the adaptation of sustainable LULC practices. The continuous monitoring of bare land restoration, conserving greenery, including forest and bush/scrubland, rehabilitating depleted and infertile lands and strict restriction of further expansion of cultivated land. Thus, it is necessary to put into action sustainable land use planning and management in the study area to reduce the effects of LULC Changes. Conserving water, soil, and forest covers with the advancements of the alteration of livelihood for local communities. Likewise, government and non-governmental organization's collaborations enhance and enforce the strategies to mitigate and prevent further negative impacts of LULC Changes in the study area, *Gal Oya.*

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