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ANALYSIS OF LONG TERM LAND USE AND LAND COVER DYNAMICS IN GALLE DISTRICT USING DEEP LEARNING ON LANDSAT IMAGERY (2003 – 2024)

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ABSTRACT

Due to population growth and the increasing demands of human activities, land use across the world has become highly diverse. Within a limited land area, land utilisation continues to expand intensively. In this context, Remote Sensing and Geographic Information Systems enable accurate monitoring and assessment of Land-Use and Land-Cover (LULC) changes. By applying different analytical techniques, geospatial technologies are widely used to assess land-use and land-cover dynamics. However, a considerable number of researchers still rely heavily on conventional classification approaches. With the advancement of modern technology, this study examines how LULC patterns can be identified and enhanced through deep learning-based techniques. The Galle District was selected as the study area, and Landsat imagery from the years 2003, 2014, and 2024 was analysed. The results reveal a rapid increase in built-up areas, which expanded from 1,206.7 km² in 2003 to 1,481.1 km² by 2024. In contrast, forest cover experienced a significant decline, decreasing from 368.04 km² in 2003 to 106.43 km² in 2024. Water bodies and barren lands also show a reduction in 2024 when compared to 2003. Accuracy assessment of the classified data indicates that Producer's Accuracy remained above 85% throughout the entire study period, while User's Accuracy demonstrated comparable values. Over the study period, the conversion of land cover into land-use has intensified considerably. As a result of these transformations, numerous environmental and urban challenges have emerged within the Galle District. These include increased flooding, land degradation, coastal erosion, and rising lower-atmospheric temperatures. Consequently, the findings emphasise the importance of sustainable urban development and the implementation of systematic land-use planning strategies.

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1.INTRODUCTION

In analyses of the interactions between humans and the environment, the concepts of land-use and land-cover (LULC) serve as fundamental indicators. Human activities such as population growth, urbanisation, industrialisation, and economic development are rapidly transforming global land-use patterns. These changes exert significant impacts on the stability of environmental systems and sustainable development (Zhao et al., 2023). In particular, coastal regions, where the dual influence of natural and human factors is highly pronounced, provide critical insights into the causes of changes in land-use and land-cover (Talukdar et al., 2020).

The Galle District, located in the southern coastal zone of Sri Lanka, stands out as a geographically important area for studying the dynamics of LULC due to the intensity of land-cover and human activities. The heterogeneity of urban and semi-urban areas, dynamics associated with the tourism industry, and contributions from agriculture and industry act as drivers of this variability. Furthermore, over the past several decades, these factors have had a significant impact in bringing about various changes and transformations. Being a region sensitive to coastal erosion, flooding, and sea-level rise, Galle District offers a valuable context for the study of long-term changes in LULC, further enhancing the practical relevance and scientific value of such analyses (Zhao et al., 2023).

RS technology enables coverage of extensive areas and provides the capability for continuous, uninterrupted data acquisition. As a result, it has become a primary scientific tool for monitoring changes in LULC. The Landsat satellite program, offering a multi-temporal dataset spanning over 40 years with medium spatial resolution, is particularly well-suited for studying long-term LULC changes at a regional scale (Talukdar et al., 2020; Zhao et al., 2023). However, some limitations of conventional classification methods are evident in the results. Techniques such as maximum likelihood, support vector machines (SVM), and random forest (RF) show various constraints, particularly in accurately representing the spatial variability of temporal features (Vali et al., 2020).

Conventional RS is now gradually shifting toward modern approaches. The weaknesses inherent in traditional methods are being overcome, and the accuracy and quality of results in newer approaches are significantly higher. In particular, deep learning techniques, such as convolutional neural networks (CNNs), provide highly reliable results in identifying LULC. These models can automatically learn multi-layered and multi-dimensional spatial features from Landsat imagery, making them more dependable compared to conventional methods (Zhao et al., 2023; Talukdar et al., 2020; Applied Computing and Geosciences, 2025). Integrating Deep Learning (DL) models with multi-temporal Landsat imagery enables a deeper analysis of long-term LULC dynamics and patterns of land-use change (Zhao et al., 2023; Applied Computing and Geosciences, 2025).

Accordingly, the primary objective of this study is to spatially and temporally analyze LULC through a comprehensive classification based on deep learning. Long-term analyses will be conducted using Landsat imagery.

The results of this research are expected to make a significant contribution by identifying land-use trends, quantitatively assessing land-cover transformations, and providing a scientific basis for sustainable land management. In addition to monitoring and classification, understanding the driving factors behind LULC changes is crucial for effective planning and management. Socioeconomic factors, including population density, infrastructure development, and industrial expansion, interact with natural processes such as coastal erosion, sedimentation, and climate variability to shape the landscape of the Galle District. By combining remote sensing data with GIS analyses, it is possible to map and quantify these interactions, revealing spatial patterns of urban sprawl, agricultural expansion, and natural habitat loss. Furthermore, incorporating temporal analyses allows for the identification of trends and hotspots of change, providing insights into areas most vulnerable to environmental stress. This integrative approach not only enhances the understanding of the human-environment nexus but also supports evidence-based decision-making for coastal zone management, urban planning, and environmental conservation. Ultimately, these insights can guide policymakers in implementing sustainable development strategies that balance socioeconomic growth with ecosystem protection.

2. LITERATURE REVIEW

2.1 LULC Dynamics and Environmental Monitoring

LULC is an important indicator in identifying changes in ecosystems. Both natural and human activities cause changes in LULC. Urbanisation, agricultural activities, deforestation, population growth, and the development of industrial processes have strong effects on these changes. Studying these changes in time and space is of great importance for environmental management, urban planning, resource conservation, and the creation of various policies (Foody, 2002).

In many parts of the world today, rapid changes in land use occur due to population growth and economic development. Accordingly, the impact on land cover is also high. The impact on the environment and socio-economic fields can be successfully identified through long-term studies and research. Modern geographic methods such as RS and GIS have become important for this reason (Congalton & Green, 2019).

Moreover, analysing LULC changes over time provides valuable insights into the patterns, intensity, and drivers of environmental transformation. RS allows for the collection of consistent and repeatable data across large areas, making it possible to detect subtle changes that may not be visible through ground surveys alone. When combined with GIS, these technologies enable the integration of spatial and temporal information, allowing researchers to model trends, predict future changes, and identify areas at risk of degradation. Long-term monitoring can reveal critical processes such as urban sprawl, deforestation, wetland loss, and the expansion of agricultural land, which have direct implications for biodiversity, water resources, and soil health. Additionally, understanding these dynamics supports the development of targeted management strategies, guiding policymakers and planners in sustainable land-use practices.

Ultimately, this approach strengthens the capacity to balance human development with environmental conservation, ensuring resilient ecosystems for future generations.

2.2 RS and Landsat Imagery for LULC Analysis

RS is used to study changes in the land, and through it, long-term changes in the land can be detected spatially. The Landsat satellite is the most widely used of the various satellite programs. Especially since the majority of research is used for ease of acquisition and without incurring financial costs. From 1972 to the present, Landsat has provided a large amount of data about the Earth through various programs (National Aeronautics and Space Administration, 2023). Landsat satellites provide multispectral data. This makes it easier to identify various features of the Earth. It makes it easier to identify forests, water bodies, urban areas and bald areas, as well as other important areas (U.S. Geological Survey, 2022). Landsat satellites provide multispectral data to identify those features further. Using data obtained from satellites such as Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 OLI, land use changes can be analysed over several decades. Therefore, Landsat data is considered a very important resource for environmental research and geographic analysis.

In addition, the continuous temporal coverage of Landsat satellites allows researchers to perform multi-decadal analyses of LULC changes, providing a comprehensive understanding of landscape dynamics. By utilising time-series data, it is possible to detect trends in urban expansion, deforestation, agricultural development, and natural habitat loss, as well as seasonal and interannual variations in vegetation and water bodies. The moderate spatial resolution of Landsat imagery strikes a balance between coverage area and detail, making it suitable for regional-scale studies while still capturing fine-scale features. When combined with advanced image processing techniques, such as classification algorithms and change detection methods, Landsat data enables accurate mapping and quantification of land transformations. Furthermore, its integration with GIS facilitates the assessment of spatial patterns, environmental impacts, and potential drivers of change. Consequently, Landsat imagery remains a cornerstone in environmental monitoring, sustainable land management, and evidence-based policymaking for ecosystem conservation.

2.3 Traditional Machine Learning Approaches for LULC Classification

In RS LULC research, pixel-based image classification methods were primarily used. Methods such as Maximum Likelihood Classification were widely used in satellite data classification. These traditional methods are limited in terms of accuracy in identifying the landscape more successfully. Over time, due to the development of technology and the advancement of computer languages, the use of Machine Learning algorithms has become widespread (Hamidreza Khatami, Hooman Mountrakis, & Stefano V. Stehman, 2016). The accuracy has increased compared to traditional classification methods through the use of algorithms such as Random Forest (RF), Support Vector Machine (SVM) and Decision Tree. The use of these algorithms has made it possible to identify the complex relationships in multispectral imagery. However, these machine learning methods have other limitations. Often, these methods require manual feature extraction. Also, the detection of spatial patterns in satellite imagery is limited. Therefore, more attention has been paid to the use of modern DL technologies.

2.4 DL Approaches in LULC Classification

DL, as a cutting-edge technological approach in the field of Artificial Intelligence, is currently very popular. It has the ability to handle and analyse a very large dataset more conveniently and efficiently. DL has capabilities beyond human intelligence. Deep neural networks can quickly and automatically identify complex patterns in data. Therefore, DL is extremely important in successfully analysing satellite imagery. Among deep learning models, CNNs are most commonly used for Landsat imagery classification (Ian Goodfellow, Yoshua Bengio, & Aaron Courville, 2016). Since CNNs can identify spatial features, textures, and patterns in images, classification accuracy increases. In addition, all analyses can be performed more successfully and efficiently. According to research, it has been found that more than 90% classification accuracy can be achieved by using CNN models. This shows that DL is very useful for RS data analysis (Xiao Xiang Zhu et al., 2017)`.

Furthermore, the application of deep learning in LULC studies extends beyond simple classification. CNNs and other deep neural network architectures can be combined with multi-temporal satellite datasets to detect changes over time, allowing for dynamic monitoring of urban expansion, deforestation, agricultural shifts, and natural habitat degradation. These models are also highly adaptable, capable of integrating multispectral and even hyperspectral data, which enhances the detection of subtle differences in vegetation, soil, and water features. When paired with GIS, deep learning outputs can be spatially analysed to identify trends, hotspots of change, and areas vulnerable to environmental stress. This integrative approach not only improves the precision of environmental assessments but also supports decision-making for sustainable land management, urban planning, and disaster risk reduction. As a result, deep learning has become an indispensable tool in modern RS research, significantly advancing the ability to understand and manage Earth's changing landscapes.

2.5 DL and Long-Term Change Detection

DL methods are not only effective in identifying LULC, but also in identifying highly complex land patterns. They are of great importance not only in classifying LULC, but also in identifying temporal changes and change detection over time. Land use changes can be identified by comparing data obtained from satellite imagery at different times. The outputs obtained using DL models are of higher quality. Since they can obtain very successful results when compared with the terrain, changes can be identified with greater accuracy. Furthermore, using technologies such as transfer learning, a model trained in one area can be used in other areas. This is especially useful for research in data-poor areas (Xiao Xiang Zhu et al., 2017).

In addition, DL approaches facilitate the integration of multi-source and multi-temporal satellite data, which enhances the ability to analyse seasonal, annual, and long-term LULC changes. Techniques such as semantic segmentation allow for pixel-level classification, capturing fine-scale spatial patterns that traditional methods often overlook. This enables more precise mapping of heterogeneous landscapes, including mixed urban-agricultural zones, fragmented forests, and coastal areas prone to erosion or flooding. Moreover, the high generalisation capacity of DL models, especially when combined with transfer learning, allows researchers to apply pre-trained networks across different regions and datasets, reducing the need for extensive local training data. These capabilities make deep learning an indispensable tool for monitoring environmental dynamics, supporting evidence-based policy-making, and guiding sustainable land management practices. Ultimately, the integration of DL into RS strengthens both the accuracy and efficiency of large-scale geospatial analyses.

2.6 Research Gap

Research on LULC using remote sensing has become a widely adopted approach worldwide due to its ability to provide accurate, consistent, and large-scale environmental information. Numerous studies have successfully applied traditional classification and machine learning (ML) techniques to monitor and analyse LULC dynamics in various regions. However, in the context of Sri Lanka, particularly in the Southern Province, the application of advanced deep learning techniques in this field remains relatively limited. The Galle District, with its unique combination of coastal landscapes, urban centres, tourism hubs, and agricultural zones, has experienced significant land-use transformations over recent decades. Urban expansions, the growth of the tourism industry, infrastructural development, and shifts in agricultural practices have all contributed to changes in land cover patterns, affecting both the natural environment and socio-economic conditions. Despite these ongoing transformations, few studies have utilised long-term multi-temporal satellite datasets, such as those provided by the Landsat program, in combination with DL models to comprehensively analyse these changes. Therefore, investigating long-term LULC dynamics in Galle District using DL techniques will not only enhance the understanding of spatial and temporal patterns but also provide valuable insights for sustainable planning, environmental management, and policy formulation in the region.

2. Methodology

3.1 Study Area

Galle District, located along the southeastern coastal belt of Sri Lanka, is used here as the study area. Galle District is particularly notable for its tourism industry as well as its diverse agricultural zones. Covering an area of 1,652 km2, Galle District is bounded to the south and west by the ocean, to the east by Matara District, and to the north by Kalutara and Ratnapura Districts. It is located within the Southern Province of Sri Lanka and lies between Northern latitudes 50 95' – 60 45' and Eastern longitudes 800 05' – 800 55' (Figure1).

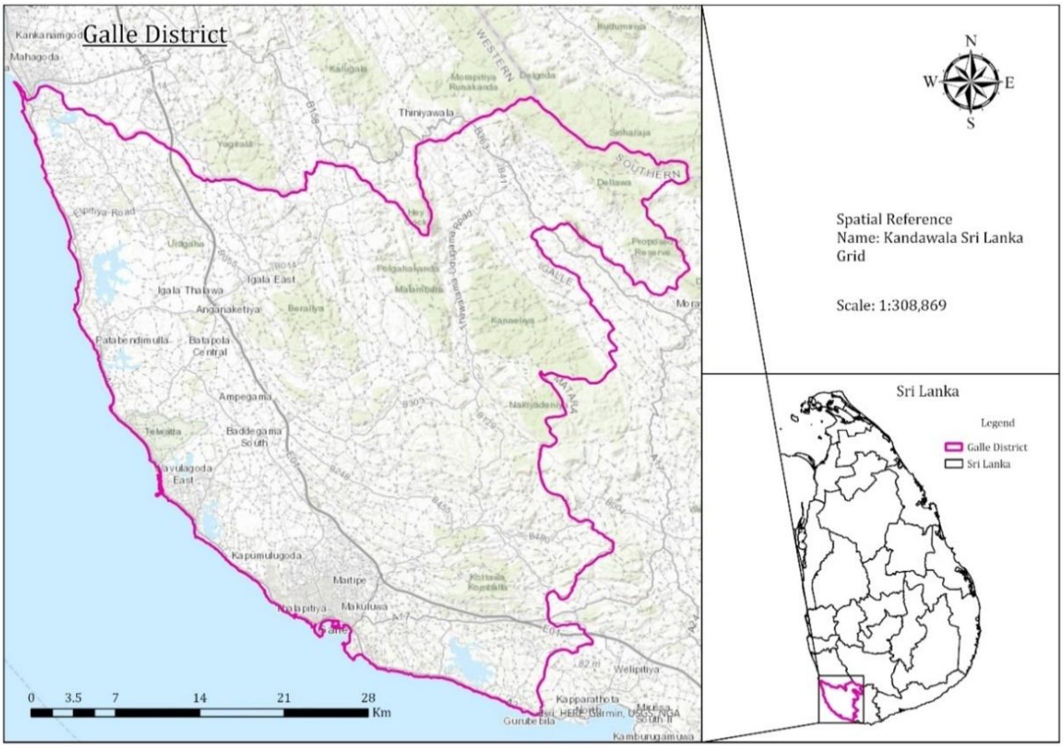


Figure 1: Map of the study location – Galle District
Source: Survey Department of Sri Lanka administrative boundary data, 2026

3.2 Data Collection

Landsat satellite images used in this study were obtained from the United States Geological Survey (USGS) Earth Explorer platform (http://earthexplorer.usgs.gov/). Landsat 7 ETM+ imagery acquired on 27 January 2003, Landsat 8 OLI imagery acquired on 26 March 2014, and Landsat 8 OLI imagery acquired on 02 February 2024 were selected for analysis. These acquisition dates were intentionally selected to provide a 21-year temporal interval, which is sufficiently long to capture significant LULC transformations while minimising the influence of short-term environmental variability. The 2003 image was chosen as the historical baseline because it represents land conditions before the rapid urban expansion and infrastructure development that occurred during the last two decades. The 2014 image was selected as an intermediate period to capture transitional landscape changes and because it is among the earliest operational datasets acquired by Landsat 8, launched in 2013, which provides improved radiometric resolution, enhanced spectral characteristics, and superior geometric accuracy compared with previous Landsat sensors. The 2024 image represents the most recent conditions, enabling an assessment of cumulative LULC changes over two decades. Furthermore, all images were acquired during the dry season (January–March) to minimise cloud cover, atmospheric disturbances, and seasonal vegetation variability, thereby improving image comparability and classification accuracy. Landsat imagery was selected because the NASA–USGS Landsat program provides the longest continuous global Earth observation record with standardised 30 m spatial resolution, making it highly suitable for reliable multi-temporal change detection. All imagery was obtained in the WGS 84 coordinate reference system to ensure spatial consistency and accurate temporal comparison across datasets.3

3.3 LULC Classification

The workflow presented in Figure 2 illustrates a comprehensive methodology for LULC classification using deep learning techniques. Initially, Landsat 7 and 8 imagery undergo pre-processing to correct for atmospheric effects, sensor noise, and geometric distortions, ensuring that the data is clean and ready for analysis. Composite bands are then created to enhance spectral information, which is crucial for distinguishing different land-cover types. Training data is generated by selecting representative samples for each LULC class, which are subsequently exported to train the DL model, such as a CNN. Once trained, the model classifies the raster imagery, producing an initial LULC map. Post-processing steps, including filtering and smoothing, are applied to refine the classification results and eliminate noise.

Accuracy assessment is conducted in parallel to validate the model's performance. Ground truth or reference data is used for validation sampling, and a confusion matrix is generated to calculate metrics such as overall accuracy, producer's accuracy, user's accuracy, and the Kappa coefficient. Finally, multi-temporal analysis enables change detection between 2003 and 2024, resulting in a final change detection map that highlights areas of land-cover transformation over time. This integrated approach ensures both spatial and temporal reliability in LULC mapping, providing valuable insights for environmental management and sustainable planning.

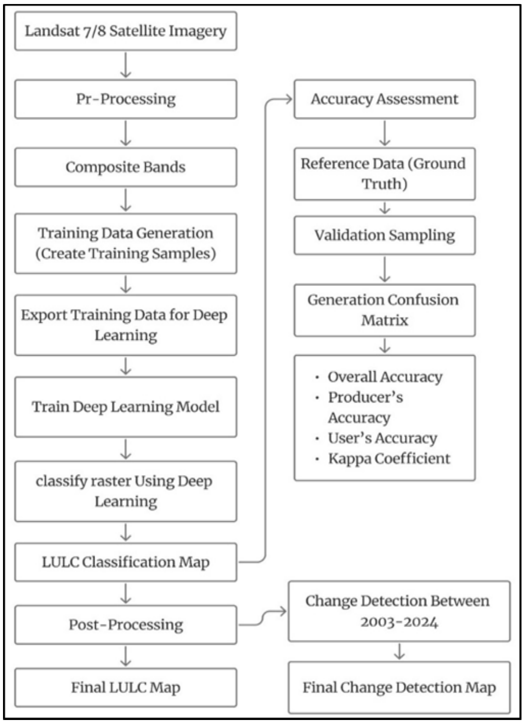


Figure 2: Methodological Workflow for Spatio-Temporal LULC Classification and Change Detection (2003–2024)

Source: Prepared by the Author,2026

4. Results and Discussion

4.1 Spatio-Temporal Pattern of Lulc in Galle District (2003-2024)

From 2003 to 2024, the Galle District shows several distinctive changes in LULC. In particular, land-use has increased rapidly, while land-cover has declined during the same period. Factors such as population concentration, development projects, and various human activities have contributed to the rapid expansion of land-use. Within the Galle District, a clear expansion of land-use can be observed around the Galle Municipal Council area as well as inland from the coastal zone during the period 2003–2024.

Table 1: Area-wise distribution of LULC classes in the Galle District

LULC	Year		
	2003	2014	2024
Barren Lands	20.48 Km^2	7.68 Km^2	8.23 Km^2
Vegetation Cover	368.04 Km^2	197.75 Km^2	106.43 Km^2
Buildup Area	1206.7 Km^2	1388.8 Km^2	1481.1 Km^2
Water Bodies	20.52 Km^2	21.45 Km^2	19.93 Km^2

Source: Prepared by the Author based on analysis,2026

During the analysis of the relevant time period, two distinctive features clearly stand out. These are the rapid growth of land-use driven by urbanization and the diverse needs of the population, and the rapid decline of land-cover. Barren land, water bodies, and vegetation cover show a noticeable decrease in association with the expansion of land-use. A clear relationship between changes in land-use and land-cover is evident in the Galle District during the period from 2003 to 2024. Notably, this relationship is an inverse one, where increases in land-use correspond with decreases in land-cover.

By 2003, vegetation cover extended over an area of 368.04 Km2. By 2024, this value had declined to 106.43 Km2. In particular, the rapid reduction of natural forest cover has occurred due to the expansion of human settlements, large-scale development projects, and agricultural development plans. When examined from 2003 to 2024, the percentage reduction in natural forest cover is shown to be 71.1%. This trend has the potential to become a common issue across the entire region, and as a result, it may lead to numerous future social, economic, and environmental problems. Compared to natural vegetation cover, a reduction in barren land and water bodies can also be identified. Although barren land shows a significant decrease of 59.8% from 2003 to 2024, the reduction in water bodies is relatively minimal. A slight decline of 2.9% can be observed in water bodies during the same period.

Although land cover has gradually declined, a rapid increase in land-use can be clearly identified within the region. In 2003, land-use covered an area of 1206.7 Km2, which increased to 1481.1 Km2 by 2024. This represents a growth percentage of 22.7% across the entire region. As land-cover progressively decreases, a corresponding gradual increase in land-use can be observed

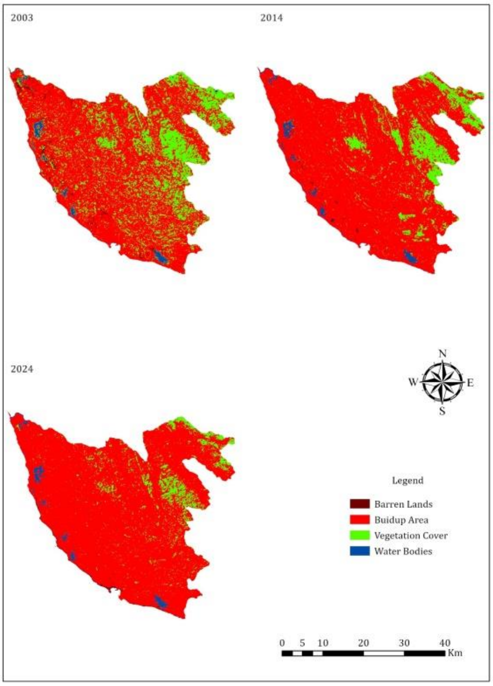


Figure 3: Spatial Distribution of LULC in the Galle District for 2003, 2014, and 2024
Source: Prepared by the authors using Landsat imagery from the U.S. Geological Survey and GIS analysis, 2026

During the year 2003, land-use was predominantly concentrated within the coastal zone. In particular, a high intensity of land-use can be identified along the main road extending from Galle city toward Ambalangoda and the Kalutara District. As the coastal zone of the Galle District represents an important area for the tourism industry, a high level of urbanisation is clearly evident within this region. In contrast, as one moves progressively inland, land-use displays a relatively lower pattern. This can be mainly attributed to lower population density and the comparatively slower pace of development in the interior areas of the Galle District.

By the year 2014, a noticeable change in this situation can be observed. Land-use increased rapidly, alongside the implementation of several large-scale development projects. The Southern Expressway and numerous major development projects associated with it expanded across the region, contributing to a rapid inland expansion of land-use within the Galle District. Compared to 2003, a significant transformation across the entire region is evident by 2014.

Major highway development projects, together with agricultural development plans promoting rubber, coconut, and minor export crops, led to an increase in land-use and a corresponding decline in natural forest cover. Barren land areas in the coastal zone that were previously unsuitable for use show a reduction from 2003 to 2014. In particular, the concentration of large hotels and other tourist facilities along the coastal belt resulted in a decline in available usable land. Consequently, previously unused or barren lands were converted into built-up areas through large-scale development initiatives. Urban pressure along the coastal zone emerges as a distinctive characteristic of the Galle District during this period.

An increase in urban pressure can be identified in the years 2014 and 2024. In particular, urban expansion shows a pattern of spreading from the coastal belt towards inland urban centres. Especially from major urban centres such as Galle, Ambalangoda, and Hikkaduwa, urban expansion and the expansion of land-use into inland areas can be identified along major highways and development planning corridors.

Table 2: Accuracy Assessment of LULC Classification (2003, 2014, 2024)

LULC	2003		2014		2024	
	Producer's Accuracy (%)	User's Accuracy (%)	Producer's Accuracy (%)	User's Accuracy (%)	Producer's Accuracy (%)	User's Accuracy (%)
Barren Lands	85	85	90	85.7	85	85
Water Bodies	85	85	90	85.7	85	85
Buildup Area	87.1	87.1	88.6	88.6	88.6	88.6
Vegetation Cover	88.9	88.9	88.9	88.9	90	88
Overall Accuracy (%)	87.5		88		87	
Kappa Coefficient	0.86		0.87		0.86	

Source: Prepared by the Author Based on Analysis, 2026

In particular, an examination of the overall process indicates that the overall accuracy value ranges between 87-88%. The Producer's Accuracy and User's Accuracy values also fall within the range of 85-90%, which is noteworthy. The Kappa Coefficient value lies between 0.86 and 0.87, reflecting a high level of agreement and representing a significant characteristic of the analysis. Overall, a high quality of reliable results can be identified from the analytical information derived from both ground truth data and satellite imagery.

The Galle District holds a distinctive importance within Sri Lanka's tourism industry, and as a result, it exhibits considerable temporal diversity in LULC. The district experiences a highly diversified tourism sector, ranging from coastal-based tourism to various other forms of tourism activities. The development of tourism-attractive centres has led to a rapid increase in land-use intensity. Furthermore, the Southern Expressway and its associated development plans have significantly influenced the diversity of land-use patterns in the Galle District. The growth of Southern Expressway interchanges such as Pinnaduwa, Imaduwa, Baddegama and Kurundugahahetekma has further intensified these impacts.

In addition, the expansion of inland transportation hubs and the widespread growth of the fisheries industry have contributed to noticeable temporal dynamics in land-use within the district. The extensive cultivation of coconut, cinnamon, rubber, minor export crops, as well as oil palm plantations, has also resulted in a broad diversity of land-use types. Consequently, barren land-cover is gradually diminishing, with such areas increasingly being converted for various human activities.

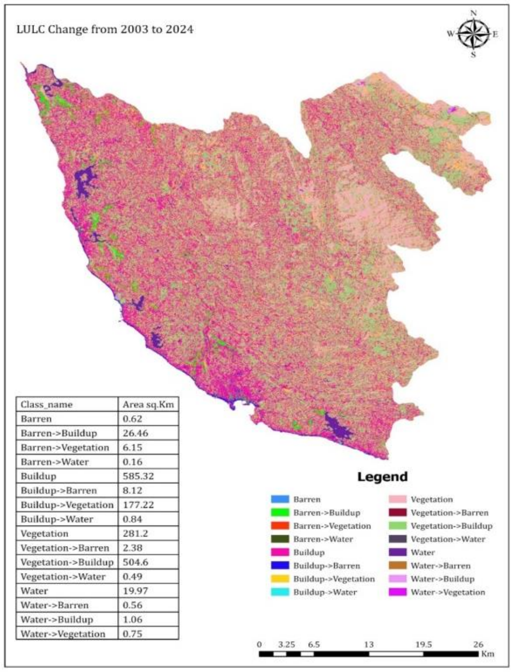
Between 2003 and 2024, the LULC dynamics observed in the Galle District exhibit patterns that are consistent with those reported in both Sri Lankan and international studies. Research conducted in the Colombo, Gampaha, and Kandy districts indicates that rapid expansion of built-up areas has occurred due to population growth, infrastructure development, and intensified economic activities, accompanied by a significant reduction in natural vegetation cover (Herath et al., 2018; Perera et al., 2019). In the Galle District, the emergence of urban and sub-urban hotspots, particularly along the coastal zone, driven by tourism-oriented development and the presence of major transportation corridors, represents a distinctive characteristic (Ranagalage et al., 2017). This pattern reflects land-use dynamics commonly observed in regions where the tourism industry plays a dominant role (Dewan & Yamaguchi, 2009). Furthermore, the outward expansion of land-use into interior areas following the development of major highways and expressways has been widely documented in South Asian studies (Perera et al., 2019). The observed reduction of vegetation cover exceeding 70% in the Galle District demonstrates strong similarities with reported trends in tropical regions, revealed by the conversion of forested and agricultural lands into urban and semi-urban land uses. Overall, the LULC dynamics of the Galle District closely align with the spatial and temporal patterns documented in existing literature, thereby reinforcing the reliability and significance of the findings of this study. These observed changes highlight the urgent need for sustainable land-use planning and effective environmental management strategies in the Galle District. The continuous expansion of built-up areas at the expense of natural vegetation may lead to increased vulnerability to environmental hazards such as flooding, soil erosion, and coastal degradation. Furthermore, the decline in vegetation cover can negatively impact biodiversity, ecosystem services, and local climate regulation. Therefore, integrating geospatial technologies with policy frameworks is essential to monitor and manage these changes more effectively. The adoption of sustainable development practices, including controlled urban expansion, conservation of green spaces, and protection of sensitive coastal ecosystems, will be crucial in mitigating adverse impacts. Such measures can help ensure a balanced relationship between development and environmental sustainability in the long term.

4.2 LULC Change Detection from 2003 to 2024

Between 2003 and 2024, LULC changes have occurred in various forms due to multiple driving factors. By 2024, noticeable changes can be clearly identified in vegetation cover, water bodies, built-up areas, and barren land. Barren land, which is generally considered unsuitable for use, shows a significant reduction in 2024 compared to 2023. In particular, by 2024, barren land covered only 0.62 Km2. Although barren land occupied an area of 20.48 Km2 in 2023, by 2024 approximately 26.46 Km2 of such land had been converted to meet human requirements. This trend highlights the extensive utilisation of marshlands, wetlands, riverbanks, and coastal areas for various construction activities. It is evident that even lands previously unsuitable for human use are being modified and adapted to fulfil human needs. Furthermore, certain development projects have led to the conversion of mangroves and environmentally sensitive conservation areas for construction purposes, which can be clearly identified. Overall, a gradual decline in barren land is observed throughout the entire region. When no other suitable land is available for human use, attention is increasingly directed toward the utilisation of barren land. In addition, these lands are also being converted for various agricultural activities, including crop cultivation.

Compared to 2023, vegetation cover shows extensive conversion to meet human requirements. Approximately 504.6 Km2 of vegetation cover has been transformed into built-up areas. This transformation is particularly evident in relation to the construction of the Southern Expressway, which has significantly intensified land use in the region. In addition, vegetation-covered areas are increasingly utilised for tourism development, fisheries-related activities, and agricultural operations. The Galle District contains several environmentally sensitive ecosystems within Sri Lanka, many of which have been converted to meet human demands. Furthermore, by 2024, vegetation cover has also been transformed into vacant or degraded lands as a result of adverse conditions arising from climate change and environmental sensitivity. By 2024, the reclamation of water bodies for various development activities is also clearly evident. The construction of hotels, tourist resorts, and major road networks has led to the infilling of certain aquatic ecosystems, which stands out as a significant trend. Overall, the conversion of land-cover into land-use is occurring at a very rapid rate.

The area that remained under land-use from 2003 to 2024 extends over 585.32 Km2. A substantial increase in built-up areas can be identified across the entire region. Land-cover types such as barren land, water bodies, and vegetation have been converted into built-up areas at a notably high rate. The rapid increase in land-use intensity is primarily driven by population growth, migration, expansion of the tourism industry, and the growth of urban and peri-urban centres. In the Galle District, a clear inland expansion of urbanisation originating from the coastal belt can be distinctly observed. The rapid conversion of LULC is a common characteristic evident throughout the entire region over the study period.



Class_name	Area sq.Km
Barren	0.62
Barren->Buildup	26.46
Barren->Vegetation	6.15
Barren->Water	0.16
Buildup	585.32
Buildup->Barren	8.12
Buildup->Vegetation	177.22
Buildup->Water	0.84
Vegetation	281.2
Vegetation->Barren	2.38
Vegetation->Buildup	504.6
Vegetation->Water	0.49
Water	19.97
Water->Barren	0.56
Water->Buildup	1.06
Water->Vegetation	0.75

Figure 4: LULC change detection in the Galle District from 2003 to 2024
Source: Prepared by the authors using Landsat imagery from the U.S. Geological Survey and GIS analysis, 2026

The temporal changes in LULC within the Galle District reflect trends commonly identified in studies conducted in Sri Lanka as well as in other developing countries (Perera et al., 2018). Several issues can be identified, including the conversion of low-value and underutilised barren lands to meet increasing human needs, along with escalating conflicts arising from limited land availability (Seto et al., 2012; Lambin & Meyfroidt, 2011). In Sri Lanka, similar to other developing nations, numerous studies on urbanisation and land-use have extensively examined changes in LULC patterns. Previous studies have clearly demonstrated that the conversion of vegetation cover into built-up areas has accelerated, particularly due to major infrastructure development projects such as the Southern Expressway (Ranaweera et al.,2019). The expansion of land-use and commercial activities along the expressway and its surrounding areas has emerged as a prominent characteristic (Dissanayake et al., 2020). Furthermore, studies conducted in the Colombo and Gampaha districts indicate that the growth of the tourism industry and population increase have significantly contributed to the intensification of land-use. The reclamation and transformation of water bodies, wetlands, and mangrove ecosystems identified in this study represent a major environmental issue reported in coastal-region studies conducted in southern Sri Lanka and across South Asian countries (McGranahan et al.,2007; Wijesekara et al.,2021). Accordingly, this study confirms that the rapid conversion of land-use and land-cover observed in the Galle District is directly associated with coastal urbanisation, infrastructure development, and broader socio-economic influences. These findings further emphasise the critical environmental implications associated with rapid land-use transformation in the Galle District. The large-scale conversion of vegetation, wetlands, and other natural land-cover types into built-up areas not only alters the physical landscape but also disrupts ecological balance and reduces the resilience of ecosystems. The loss of mangroves and wetlands, in particular, increases the vulnerability of coastal zones to flooding, storm surges, and sea-level rise. Additionally, the reduction of green cover contributes to urban heat island effects, decreased air quality, and loss of biodiversity. These changes can also affect local livelihoods, especially those dependent on agriculture, fisheries, and ecosystem services. Therefore, it is essential to incorporate sustainable land management strategies, enforce environmental regulations, and promote conservation initiatives. Strengthening the integration of RS and GIS in monitoring processes can support timely decision-making and help mitigate the long-term environmental risks associated with uncontrolled land-use expansion.

4.3 Issues Related To LULC Changes in Galle District

Rapid urbanisation, the expansion of tourism activities, accelerated infrastructure development, and improvements in transportation networks have led to significant changes in LULC in the Galle District. According to studies conducted between 1996 and 2019, the extent of built-up land within the Galle Municipal Council area has increased by approximately 38%. This growth has occurred alongside a reduction in vegetation cover and agricultural land, as well as increased land fragmentation. Hikkaduwa and the southern coastal belt have experienced substantial development as major tourism hubs. As a result, coastal vegetation and biodiversity have been rapidly degraded. This represents a common issue observed in other coastal cities undergoing similar patterns of urban growth (Herath et al., 2018; Ranasinghe & Hettiarachchi, 2020; Seto et al., 2012).

Figure 5: Conceptual Illustration of LULC Change Impacts in the Galle District
Source: Prepared by the Author, 2026

As a consequence of these LULC changes, land surface temperature (LST) in the Galle urban area has increased significantly. Over a period of twenty-two years, the average annual temperature has risen by more than 3°C, clearly indicating the presence of the Urban Heat Island (UHI) effect. Furthermore, weakening coastal stability can be identified in the coastal zones of the Galle District. Broader studies covering the southern coastal region reveal that the conversion of agricultural and natural land-covers into built-up and modified land-covers has altered habitat structure and reduced ecological functions (Weng, 2009; Estoque et al., 2017; Gunawardena et al., 2017). Studies on tsunami inundation conducted along the coastal areas of the Galle District clearly indicate that such events are closely associated with the removal or degradation of coastal protection systems. In addition, seasonal monsoonal variability leads to periodic flooding of the Galle–Colombo main road during certain times of the year. These observations demonstrate that different land-cover types, such as coastal vegetation and urban built-up areas, directly influence the behaviour and impacts of natural hazards. Furthermore, studies carried out using geoinformatics approaches have documented a significant decline in green cover within the Galle urban area over the past few decades. This trend further confirms the ongoing replacement of natural land-covers with built-up infrastructure and urban development (Wijetunge, 2006; Dissanayake et al., 2019; Dewan & Yamaguchi, 2009).

Overall, when rapid urban expansion, the loss of vegetation and agricultural land, rising LST, and increased vulnerability to climatic and coastal hazards are considered together, it becomes evident that LULC issues in the Galle District are multidimensional and complex. These conditions highlight the critical need for sustainable land-use planning that maintains a balance between development and environmental conservation (UN-Habitat, 2020; Foley et al., 2005).

Coastal hazards are rapidly increasing within the Galle District. In particular, the degradation of coastal biodiversity has, over the long term, severely reduced flood buffering capacity, coastal resilience, and the provision of ecosystem services. The reduction of natural land-cover combined with intensified land-use has led to multiple alterations in the hydrological cycle. Decreased infiltration capacity, together with intense rainfall events, has increased flood risk, and the growing incidence of flooding in low-lying areas of the Galle District can be considered clear empirical evidence of this process (Costanza et al., 2014; Arkema et al., 2013; IPCC, 2021). The LULC trends identified in this study indicate that development in the Galle District is not following an environmentally sustainable trajectory, but rather a risk-intensifying trajectory. Although these patterns are similar to global urban expansion trends, the impacts are more sensitive and detrimental in a coastal city such as Galle. This strongly underscores the necessity of future land-use planning, effective zoning regulations, and ecosystem-based management approaches (Seto et al., 2011; Beatley, 2014; UNEP, 2019).

4.4 Sustainable LULC Management Strategies in Galle District.

The rapid LULC transformations observed in the Galle District clearly indicate the need for sustainable and integrated land management strategies, especially under pressures from urbanisation, tourism development, and infrastructure expansion. Research shows that urbanisation and associated LULC changes significantly alter local climate dynamics and environmental quality in Sri Lankan coastal cities, including Galle (Dissanayake, 2020). A key strategy involves effective land use zoning and planning regulations that protect environmentally sensitive areas. Ecological land use models that integrate environmental principles with spatial planning improve resilience and sustainability by enhancing climate resilience and stakeholder participation (Nabilla, 2025).

Ecosystem based management (EBM), including restoration of degraded ecosystems such as forests, mangrove rehabilitation, and wetland conservation, is critical for strengthening natural defences against hazards and maintaining ecosystem services. Studies on mangrove ecosystems in Sri Lanka highlight the importance of mangrove conservation and targeted restoration as part of climate resilient management strategies (Athukorala et al., 2025). Promoting green infrastructure, as an integral component of sustainable urban land management, helps mitigate the UHI effect and supports biodiversity. Reviews on urban green space research emphasise that urban vegetation and green infrastructure contribute to multiple ecosystem services, including heat mitigation, air quality improvements, and enhanced well being, aligning with Sustainable Development Goals (SDGs) for sustainable cities (Urban Climate, 2025).

Geospatial technologies such as RS and GIS are invaluable for monitoring LULC changes and supporting evidence based decision making. Advances in earth observation data and integration with machine learning enhance land monitoring, change detection, and planning efforts (Sustainable Urban Land Management, 2025). Continued use of RS and GIS tools enables real time tracking of LULC dynamics and environmental risk areas. This has been demonstrated in studies documenting built-up area increase and natural land cover decline in Sri Lanka’s urban and coastal regions (Wijesinghe & Amaraweera, 2022). Community participation and stakeholder engagement are also essential, as sustainable planning efforts benefit from local knowledge and involvement, improving policy inclusivity and compliance (Planning for Sustainability, 2025). Together, these strategies, when embedded in coordinated policy frameworks supported by strong institutional collaboration, can harmonise economic development with environmental conservation for long term sustainability.

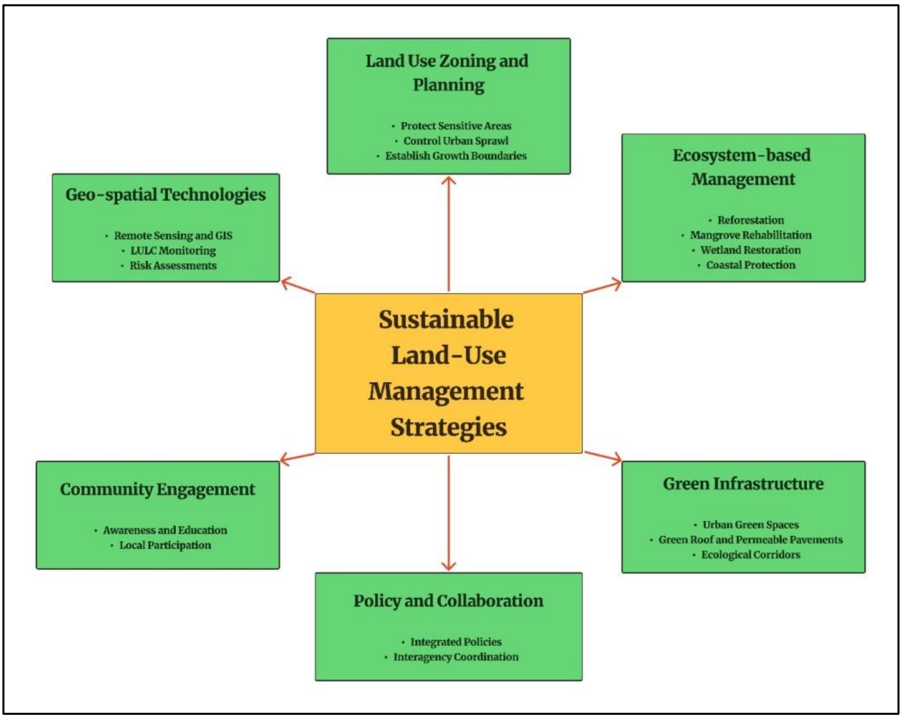


Figure 6: Land-Use Management Strategies
Source: Prepared by the Author,2026

5. CONCLUSIONS

Through traditional RS analysis techniques, numerous geospatial studies have been conducted to understand LULC dynamics. Building upon these conventional approaches, the integration of deep learning and other advanced geospatial methods has enabled more precise and automated interpretation of satellite imagery, providing a richer understanding of spatial and temporal patterns. In the context of the Galle District, a comprehensive geo-scientific investigation was conducted using multi-temporal satellite datasets to examine LULC changes between 2003 and 2024. This analysis facilitated the identification of both gradual and abrupt variations in LULC, highlighting areas experiencing significant transformation, including urban zones, coastal regions, agricultural lands, and natural ecosystems. The study revealed that rapid urban expansion, industrial growth, and tourism-related developments are the primary drivers of these LULC changes, exerting pressure on forests, wetlands, and coastal buffer zones. The findings underscore the importance of moving away from unplanned land-use practices toward more systematic, sustainable approaches. Incorporating sustainable development principles into urban planning, suburban expansion, highway and infrastructure projects, and the construction of tourism facilities is crucial to minimise environmental degradation. Furthermore, the study emphasises the necessity of developing a resilient environmental management framework that can effectively respond to climatic hazards, natural disasters, and anthropogenic environmental pressures. The integration of advanced geospatial technologies, combined with policy-level guidance and community participation, can support proactive decision-making, adaptive planning, and the implementation of mitigation measures. By prioritising sustainable LULC practices and adopting a forward-looking, science-based management strategy, the Galle District can achieve a balance between development needs and environmental conservation, thereby ensuring long-term socio-ecological resilience.

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