A Spatio-Temporal Analysis of Land Cover Change Detection Using Geo-spatial Technologies on Muthurajawela Marsh-Negombo Lagoon Wetland Complex

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Abstract: *The Muthuraj Wela Wetland, a Ramsar site in Sri Lanka known for rich biodiversity, has experienced substantial land cover changes in recent decades. Using satellite imagery and remote sensing, this study analyzed these changes from 1997 to 2023, crucial for monitoring environmental shifts. Initial assessments involved Normalized Difference Vegetation/Water Indices (NDVI/NDWI) to identify vegetation and water bodies, while the Maximum Likelihood Supervised Classification (MLSC) technique categorized land into water, marshland, settlements, vegetation, and barren land. Accuracy was ensured through Confusion Matrix analysis for each land cover class. Furthermore, a detailed post-classification analysis was conducted through Thematic Change Detection (TCD), which compared historical changes in land classes to their current status. TCD analysis illustrated that 46% of the total land cover has changed over 3 decades. From 1997 to 2023, Muthurajawela Wetland experienced significant ecosystem shifts: water areas of Negombo lagoon remained stable at 26-32%, but 90% of deep-water areas turned shallow water, indicating shoaling process which impacts lagoon water quality and habitats. Highland vegetation (agriculture, forests) decreased sharply from 26% to 6% in 2015 and 2023, indicating substantial loss due to urbanization. Marshland also decreased consistently from 15% to 6% by 2023, reflecting ongoing challenges in wetland preservation and prawn farming. Built-up areas notably increased from 18% to 38%, illustrating rapid urban expansion's impact on natural landscapes. Bare land decreased from 34% in 2015 to 23% in 2023, possibly due to changes in land management or reclamation efforts. Key changes in land cover include a significant conversion of marsh land to bare land, totaling 5.35 sq.km (4.17%), and substantial urban development, converting 11.94 sq.km (9%) from bare land to built-up areas. The findings highlight the trend towards urbanization, ecological changes affecting biodiversity, and the need for sustainable land management to preserve the ecosystem of Muthurajawela Marsh-Negombo Lagoon Wetland Complex.*

Keywords: Change Detection, Land Cover, Muthurajawela Marsh, Negombo Lagoon, Wetland

1.Introduction

1.1 Background

Wetlands include world heritage sites with significant values to ecological, biological, zoological, limnological or hydrological settings, including such phenomena as thermal features and underground rivers. (Blasco and Aizpuru,1997 cited in Haque, I and Bask, R., 2017). The Greater Colombo Economic Commission highlights that The Muthurajawela Marsh and the Negombo lagoon are situated about 10-30km North of Colombo in Gampaha district are ecological systems forming a wetland complex. (Greater Colombo Economic Commission, 1991) GCEC states that the total area of this wetland covers about 10,000 ha which consists of 3,000 ha of undeveloped marshland with Negombo lagoon measures 3100 ha (The Greater Colombo Economic Commission, 1991, p.13). The balance is made up by rivers, canals, and other water bodies, a dune belt along the coast, the shore areas of the lagoon and some other higher lands along the eastern and southern periphery of the marsh where most of the population is settled (Greater Colombo Economic Commission, 1991).

Muthurajawela Wetland, a Ramsar site, is recognized for its rich biodiversity and productive ecosystem. Despite its significance, the landscape has undergone substantial changes over decades. A protected area of 1.621 km^2 has been established, as detailed in Gazette Notification No. 1466/26 of October 13, 2006, and the northern portion of the marsh was designated a sanctuary in 1996 (Central Environmental Authority, 2023; Greater Colombo Economic Commission, 1991). The area is vital for local tourism and agriculture, with efforts in place to manage visitor impact (Muthurajawela Marsh Center, 2022).

The largest saline coastal peat bog in Sri Lanka is Muthurajawela. The marsh lagoon complex itself is said to have started approximately 5000 BC, and combined with the Negombo Lagoon, they constitute an integrated coastal wetland eco-system. Under the provisions of the code for the protection of flora and animals, the 1,777ha northern portion of the marsh was designated a sanctuary in July 1996 (Greater Colombo Economic Commission, 1991). The marsh is a significant local and tourist destination that is largely used for tourism and boat trips. Local forestry and agriculture are also supported by the region. To prevent major disturbance to the marsh environment, the staff at the Muthurajawela Marsh Centre directs visitors through the sanctuary sections. (Muthurajawela marsh center, 2022).

Understanding land cover changes, which involve categories such as vegetation, built up area and water bodies, is essential for managing natural resources and urban planning. Remote sensing and Geographic Information Systems (GIS) are valuable tools for tracking these changes and their implications for ecosystems and human activities (European Commission, 2022; Wang et al., 2020). Remote sensing and GIS facilitate the monitoring of land use changes over time, helping to address the impact of anthropogenic activities and natural events on wetlands (Willkie & Finn, 1996, cited in Haque & Basak, 2017). This study aims to fill the gap left by traditional survey methods, providing a detailed, spatially and temporally accurate picture of land use/cover changes. The findings will help in understanding the interactions between human activities and the environment, and in developing strategies for better management and conservation of the wetland complex.

Using a deductive approach, the research will select a few key variables for analysis through a factor-controlling method (Wang et al., 2020). This approach aligns with the increasing need to understand land cover changes for effective resource management and urban planning (Wang et al., 2020)

Remote Sensing (RS) and Geographic Information Systems (GIS) are essential tools for analyzing land use and cover changes. These technologies enable comprehensive evaluations of ecological and socio-economic patterns at various scales and facilitate the link between localized research and broader conservation efforts (Willkie & Finn, 1996, cited in Haque & Basak, 2017). Landscape change is crucial for understanding human-environment interactions, and tracking these changes helps in sustainable development planning (Teketay, 2001, cited in Wang et al., 2020; Lu, 2003, cited in Wang et al., 2020).

The study will employ RS and GIS to detect and analyze land cover changes in the Muthurajawela Marsh and Negombo Lagoon, reflecting both human impact and natural phenomena. This method is expected to provide insights into current changes and their implications for the wetland complex. Unlike traditional survey-based studies, this research will rely primarily on remotely sensed data with minimal field visits, addressing gaps left by conventional methods. The study also aims to enhance understanding of land cover dynamics and inform sustainable management strategies for one of Sri Lanka's most vulnerable wetland areas.

The Muthurajawela Marsh and Negombo Lagoon represent a critical wetland complex in Sri Lanka, distinguished by its rich ecological and historical significance. Despite its recognized value and the protective measures implemented by the Greater Colombo Economic Commission (GCEC) and the Central Environmental Authority, the area faces significant landscape and biodiversity changes. To address this, the study will utilize Remote Sensing (RS) and Geographic Information Systems (GIS) to analyze land cover dynamics comprehensively. By focusing on key factors such as vegetation, soil, and water bodies, this research will provide a more nuanced and accurate understanding of environmental changes than traditional survey methods. The insights gained will be instrumental in elucidating the impacts of human activities and natural processes on the wetland complex, ultimately guiding more effective management and conservation strategies.

1.2 Statement of the Problem

The Muthurajawela Marsh and Negombo Lagoon in Sri Lanka are crucial wetland systems with significant ecological, biological, and hydrological roles. According to the Greater Colombo Economic Commission's master plan (1991), the marsh and lagoon together cover 3,068 hectares and 3,164 hectares, respectively, with their surrounding areas totaling 4,462 hectares, resulting in a combined wetland area of 10,694 hectares. This wetland complex forms an integrated ecological system critical for biodiversity and ecosystem services (Greater Colombo Economic Commission, 1991).

Recent literature, such as the work by Khanh and Subasinghe (2015), reports a reduced combined area of the Muthurajawela Marsh and Negombo Lagoon to 6,232 hectares. This discrepancy indicates a significant reduction in the total extent of the wetland complex over time. The ongoing urbanization and environmental changes are likely contributing to this reduction, underscoring the need for updated and accurate assessments. When comparing these academic works, it is obvious that the total area of the wetland along with the lagoon has been diminished by extent.

In 2018 presidential investigation unit has launched an inquiry into alleged collusion among government officials regarding the Muthurajawela sanctuary landfill. The rapid urban expansion in the Colombo Metropolitan Region, with an annual population growth rate of approximately 2.5% and corresponding land development, has led to increased pressure on wetland areas. Recent satellite imagery analysis has shown a 15% reduction in wetland areas within the Colombo District between 2000 and 2020 due to construction and land reclamation activities (Haque & Bask, 2017).

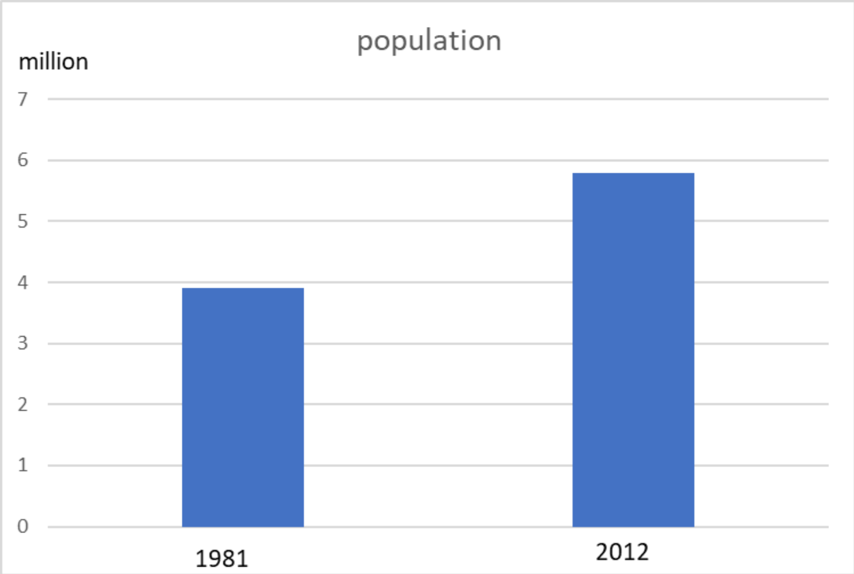


Figure 1: Population growth of Colombo metropolitan area from 1981- 2012

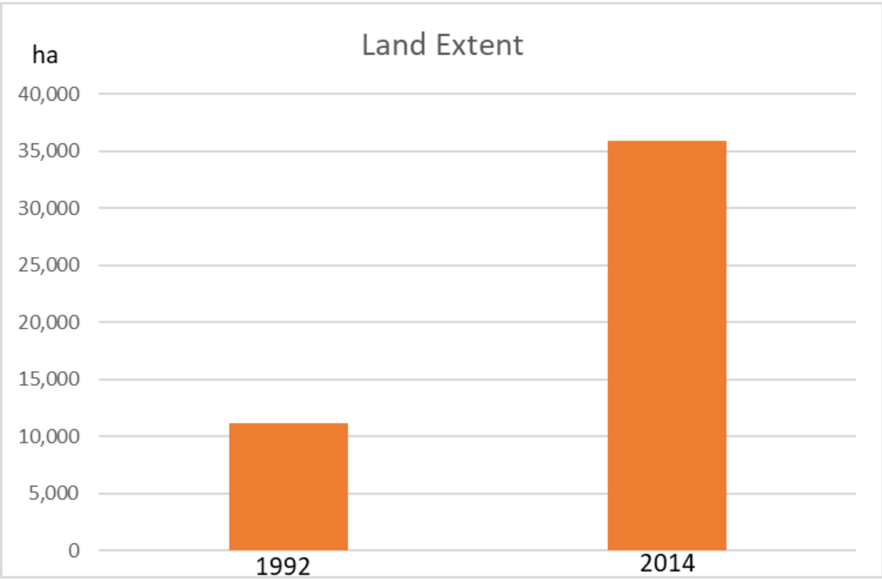


Figure 2: Land development of Colombo metropolitan area from 1981- 2014

The Muthurajawela Marsh and Negombo Lagoon face threats from urbanization, which exacerbates pollution and disrupts the natural hydrological balance. Although conservation measures, such as protected areas and buffer zones, have been established, traditional survey methods have limitations in capturing the dynamic nature of land cover changes (Central Environmental Authority, 2023).

Although more than 300,000 people live in the Muthurajawela wetland-Negombo area, just under 5,000 people live in and around the marsh itself, half of whom are squatters and about three quarters who live on unauthorized landholdings. About 80% of industries in the country are concentrated in Colombo and Gampaha Districts (United Nations Environment Program, 2001 cited in Khanh and Subasinghe, 2018) Further, the location of the Muthurajawela wetland in a rapidly developing urban area which makes it an extremely vulnerable ecosystem (IUCN, 2003 cited in Khanh and Subasinghe, 2018).

The Organization of Muthurajawela was formed in response to the government's decision to use Meethotamulla as a garbage dump, prompting residents to seek judicial intervention to protect the marsh from becoming a waste site (Organization of Muthurajawela, 2022). Scientific research (Rojas et al., 2013, cited in Wang et al., 2020) shows that landscape changes are closely linked to biodiversity loss, deteriorating water quality, increased carbon emissions, and adverse effects on ecosystems. The transformation of agricultural and forestry lands into urban areas and industrial estates has led to reduced biodiversity, loss of ecosystem services, and greater land degradation vulnerability (Li et al., 2016; Basommi et al., 2016, cited in Wang et al., 2020). Kirinde (2018) reports that a group of residents exposed environmental destruction within the Muthurajawela sanctuary, leading to the formation of the Organization for the Protection of Muthurajawela.

Landfilling has significantly increased barren lands in the area, and small-scale land reclamation by local fishermen in the Negombo lagoon should be halted to prevent water flow restrictions. Lagoon degradation, including increased water depth and dredging, threatens sea grass beds. Despite reports of accelerated silting, recent information indicates that sedimentation rates are balanced by rising sea levels (Greater Colombo Economic Commission, 1991).

Literature review identifies key factors impacting land cover changes in the Muthurajawela marsh-Negombo lagoon complex, including vegetation, settlements, water, marshland, and barren land, which are critical variables for understanding land cover dynamics.

To tackle the challenges facing the Muthurajawela Marsh and Negombo Lagoon complex, advanced technologies like Remote Sensing (RS) and Geographic Information Systems (GIS) are essential. These tools offer precise data on land cover changes and the effects of urbanization on this vital wetland area (European Commission, 2022; Wang et al., 2020). This study will leverage RS and GIS to provide a detailed, up-to-date analysis of land cover changes, aiming to fill knowledge gaps and inform effective conservation and management strategies (Willkie & Finn, 1996, cited in Haque & Basak, 2017; Greater Colombo Economic Commission, 1991).

1.3 Objective of the study

The study aims to evaluate the nature, significance, and rate of changes in the lagoon-wetland complex from 1997 to 2023, with a particular focus on uncovering the facts behind land cover changes. Specifically, it seeks to detect and analyze both past and recent land cover changes, generate detailed land cover change maps to measure area variations, and investigate the factors driving these changes by comparing land cover maps over three decades. Additionally, the study will identify areas where land cover classes have been converted to other classes during this period, providing a comprehensive understanding of land cover dynamics in the Muthurajawela Marsh-Negombo Lagoon wetland complex.

1.4 Rationale of the study

This study is distinctive in its ability to measure and analyze land cover changes over decades using Remote Sensing (RS) and Geographic Information Systems (GIS). The developed Land Use/Cover analyzing model allows for detection of environmental impacts and illegal activities affecting land cover. RS and GIS technologies enable comprehensive analysis without the need for field visits, detecting features through satellite images. These advanced technologies are crucial for updating and presenting data, aiding urban developers, policymakers, and researchers in environmental conservation and development.

The Muthurajawela Organization highlights the wetland's high biodiversity and its critical environmental services, including flood control, fisheries, and recreation. The wetland supports 125 species and 29 florae, with its value for flood management and water purification being particularly significant (Organization of Muthurajawela, 2022). However, it faces severe threats from waste disposal and other anthropogenic activities, which jeopardize its ecological integrity and services (Central Environmental Authority, 2023).

1.5 Study Area

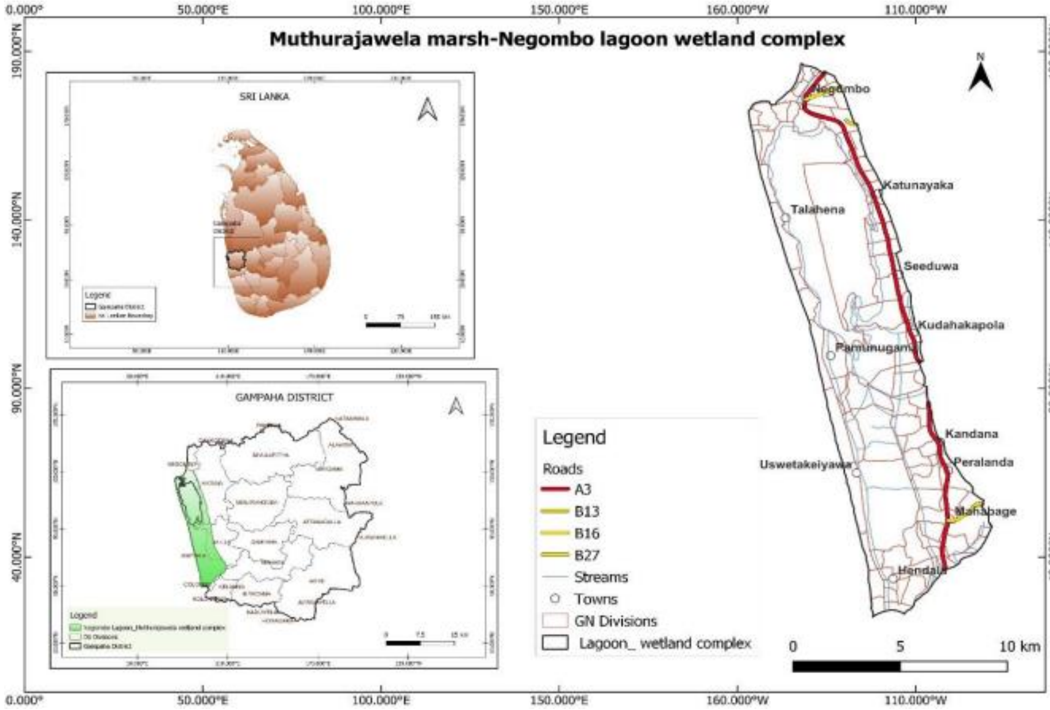


Figure 3: Location of Muthurajawela Marsh-Negombo Lagoon Wetland Complex

Muthurajawela Wetland in Sri Lanka is situated on the west coast between the Negombo Lagoon and the Kelani River, extending inland to Ragama and Peliyagoda in the Gampaha district. This wetland, along with the Negombo Lagoon, forms a 6,232 ha coastal wetland ecosystem (Khanh and Subasinghe, 2018). The daily high tide introduces seawater into the wetland, creating a biologically diverse brackish ecosystem. The current study recorded 157 plant species across 62 families, including 16 aquatic weeds, 91 grasses, 23 lianas, 17 shrubs, and 10 woody species. The area experiences 2000-2500mm of annual rainfall and an average temperature of 27°C. The soil is uniformly acidic and poorly drained with a peaty substrate, remaining saturated most of the year. Water sources include the Kelani River and the Dandugamoya stream (Khanh and Subasinghe, 2018).

2.Literature Review

2.1 Key Concepts in Land-Cover Change

Monitoring land-cover/land-use (LCLU) change is crucial for understanding environmental impacts and modeling change mechanisms at various scales (William et al., 1994; Turner et al., 1995 cited in Peiman, 2011). Remotely sensed data play a vital role in detecting and analyzing these changes, especially in areas experiencing rapid anthropogenic transformation (Howarth and Boasson 1983; Mas 1999 cited in Peiman, 2011).

Meyer (1999) highlights that while land use (e.g., agriculture, urban development) and land cover (e.g., cropland, forest) are distinct, they are closely related. Originally, "land cover" referred to vegetation types but has since expanded to include human-made structures and other environmental factors (Meyer, 1995 cited in Opeyemi, Z.A., 2006).

Remote sensing and GIS tools have significantly improved our ability to monitor LULC changes. These technologies provide detailed information on changes at both regional and global levels, utilizing various algorithms tailored to specific research needs (Chughtai, A.H. et al., 2021).

2.2 Significance of the study to ACRS Conference

A Spatio-Temporal Analysis of Land Cover Change Detection Using Geo-spatial Technologies on Muthurajawela Marsh-Negombo Lagoon Wetland Complex is highly relevant to the ACRS 2024 Conference. The conference emphasizes advancements in remote sensing and geospatial technologies, and this study utilizes these tools to analyze land cover changes over time, showcasing practical applications in environmental monitoring. The focus on this ecologically significant wetland complex aligns with the conference's themes of environmental monitoring, conservation, and sustainable land use. Additionally, the spatio-temporal analysis supports discussions on effective resource management and disaster mitigation, contributing valuable regional insights. By addressing key issues in a major Sri Lankan wetland, this research enhances the conference's discussions on similar environmental challenges across Asia.

2.3 Remote Sensing Techniques

Remote sensing techniques for detecting land-cover changes utilize both passive and active sensors. Passive sensors detect energy reflected from the sun, while active sensors generate their own energy (e.g., synthetic aperture radar) (Singh, 1989 cited in Jovanović et al., 2015). Change detection involves identifying differences in the state of an object or phenomenon over time. Techniques include direct image comparison and analysis of combined images from different times (Jovanović et al., 2007; Jovanović et al., 2011).

High-resolution satellite imagery from sources like Landsat satellites is crucial for urban studies, as fine spatial resolution helps in identifying land cover types and changes (Weber, 1994 cited in Adepoju, M.O., 2007). Multispectral sensors capture detailed spectral data that are essential for accurate land cover classification (Barnsley and Barr, 1997 cited in Adepoju, M.O., 2007).

Object-based change detection improves upon traditional pixel-based methods by analyzing image data at the object level rather than the pixel level. This technique involves segmenting an image into distinct objects or regions based on both spectral and spatial characteristics. These objects are then classified into land cover types, and changes are detected by comparing objects from different time periods.

This approach enhances accuracy by considering the spatial context of each object, which helps in reducing noise and misclassification issues common in pixel-based methods. It is particularly effective in complex and heterogeneous landscapes, such as urban areas, where spatial coherence is important for accurate change detection (Blaschke, 2010).

2.4 Applications of Remote Sensing and GIS

Remote sensing and GIS have become fundamental in monitoring LULC changes, offering cost-effective and accurate tools for environmental management (Mouat et al., 1993; Coppin and Bauer 1996). Techniques for change detection include both pixel-based and object-based classifications, with advancements in satellite technology enhancing the precision of these methods (Adepoju, M.O., 2007) The rapid growth of urban areas, particularly in developing countries, has led to significant land-cover changes. For example, Colombo's population increase from 3.9 million in 1981 to 5.8 million in 2012 resulted in a dramatic expansion of built-up areas (The World Bank, 2012 cited in Athukorala et al., 2021).

The Muthurajawela Wetland in Sri Lanka has experienced substantial land cover change, with its area reducing from 10,000 ha in 1989 to 6,232 ha in 2018 due to urban expansion and land reclamation (Greater Colombo Economic Commission, 1991; Emerton, 2005 cited in Khanh and Subasinghe, 2018). This reduction highlights the impact of increasing population and development pressures on wetland ecosystems.

2.5 Recent Advances

Modern advancements include drone mapping and terrestrial laser scanning (TLS), which offer high-resolution observations and have become crucial for fine-scale change detection in various fields (Adresen, C.G. and Schilz-Fellenz, E.S., 2023).

In Ukraine, remote sensing was used to assess the impacts of large-scale forest fires in contaminated areas, demonstrating the effectiveness of satellite data in managing disaster responses and understanding environmental impacts (Tewabe, D. and Fentahun, T., 2020).

3.Methodology

3.1 Data Collection

For the study, Landsat satellite images of Sri Lanka were acquired for three decades; 1997, 2004,2015 and 2023. All Satellite images were obtained from USGS earth explorer web portal under Landsat satellite mission. It is also important to state that the study area delineation was done according to the digital toposheets acquired by The Survey Department of Sri Lanka using administrative boundaries of digital topo sheets. These digital data was converted to World Geodetic System and brought to Universal Transverse Mercator projection in zone 44 of Northern Hemisphere.

Table 1

Details of acquired satellite images.

Satellite id	Sensor id	Path/row	Acquisition date	Spatial resolution
Landsat 5	TM	141/055	1997/02/07	30 m
Landsat 5	TM	141/055	2004/02/11	30 m
Landsat 8	OLI/TIRS	141/055	2015/04/14	30 m
Landsat 8-9	OLI/TIRS	142/055	2023/04/12	30 m

3.1.2 Geo-referencing and Mosaicking

Digital topographic sheets (Nos. 59/66) obtained from the Department of Survey were georeferenced using Bing World Map imagery as the spatial reference dataset (University of Toronto Libraries, 2023). This process involved aligning the scanned maps with geographic coordinates. The georeferenced sheets were then mosaicked into a single topographic map to delineate the study area.

3.2 Software Used

Several software tools were employed in the project:

- ArcGIS: Utilized for data display, processing, and radiometric correction of satellite images.
- QGIS: Applied for georeferencing and mosaicking digital topo sheets.
- ENVI: Used for data processing and thematic change detection analysis.
- Microsoft Word: For thesis presentation.
- Microsoft Excel: For generating bar graphs, charts, and statistical analysis.

3.3 Development of a Classification Scheme

A classification scheme was developed based on a 26-year literature review of the study area. This scheme broadly categorizes land use and cover into five types, each represented by a single digit:

Table 2

Land cover categorization

Land Class	Land Cover Category	Term of Definition
1	Water	Water body means natural or impounded surface water including a stream, river, spring, lake, reservoir, pond, wetland, tank and fountain (Law Insider, 2022)
2	Vegetation	Vegetation may be defined as the patchwork of plant species arrayed across the landscape. It includes a variety of life forms such as trees, shrubs, grasses, forbs and non-vascular plants like mosses (De Anza College, 2023). Vegetation is the plant life or total plant cover as of an area (Merriam-Webster,2023).
3	Marsh land	A marsh is a type of wetland, an area of land where water covers ground for long periods of time. Unlike swamps which are dominated by trees, marshes are usually treeless and dominated by grasses and herbaceous plants (National Geographic Society, 2022).
4	Built-up Area	A Built-up area is an area such as a town or city which has a lot of buildings in it (Collins,2023).
5	Bare land	Bare land is areas with no dominant vegetation cover on at least 90% of the area or areas covered by lichens/moss (Eurostat, 2021).

3.4 Limitations of the study

The study's spectral analysis is limited by the human eye's ability to discern tonal values and spectral changes. The Landsat satellite images used have a spatial resolution of 30 meters, which could be improved with higher resolution imagery for more accurate interpretations.

3.5 Methods of data analysis

1.Atmospheric Corrections: Adjusting satellite imagery to remove atmospheric effects, such as haze and water vapor, to enhance the accuracy of the data.

2.Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI):

- NDVI: A measure used to identify and assess vegetation cover by evaluating the difference between near-infrared (which vegetation strongly reflects) and red (which vegetation absorbs) bands.
- NDWI: Used to delineate water bodies by comparing the green and near-infrared bands, as water absorbs near-infrared light but reflects green light.

3.Image Composition: Combining multiple layers or images to create a composite image that highlights specific features or attributes for further analysis.

4.Signature Development: Creating and defining spectral signatures for different land cover classes based on their unique reflectance properties. These signatures are used in classification algorithms to categorize pixels into different land cover types.

5.Maximum Likelihood Classification: A supervised classification technique where each pixel in an image is assigned to the land cover class that has the highest probability of being the true class, based on statistical analysis of training samples.

6.Accuracy Assessment and Kappa Coefficient: Evaluating the accuracy of the classification results by comparing them to reference data. The Kappa coefficient measures the agreement between the classified data and the reference data, accounting for chance agreement.

7.Calculation of Area: Measuring the area in square kilometers for each land use/land cover type for different years to analyze changes over time.

8.Post-Classification Change Dynamics: Using thematic change detection tools to analyze and interpret changes in land cover between different time periods, assessing the dynamics and trends of land cover changes.

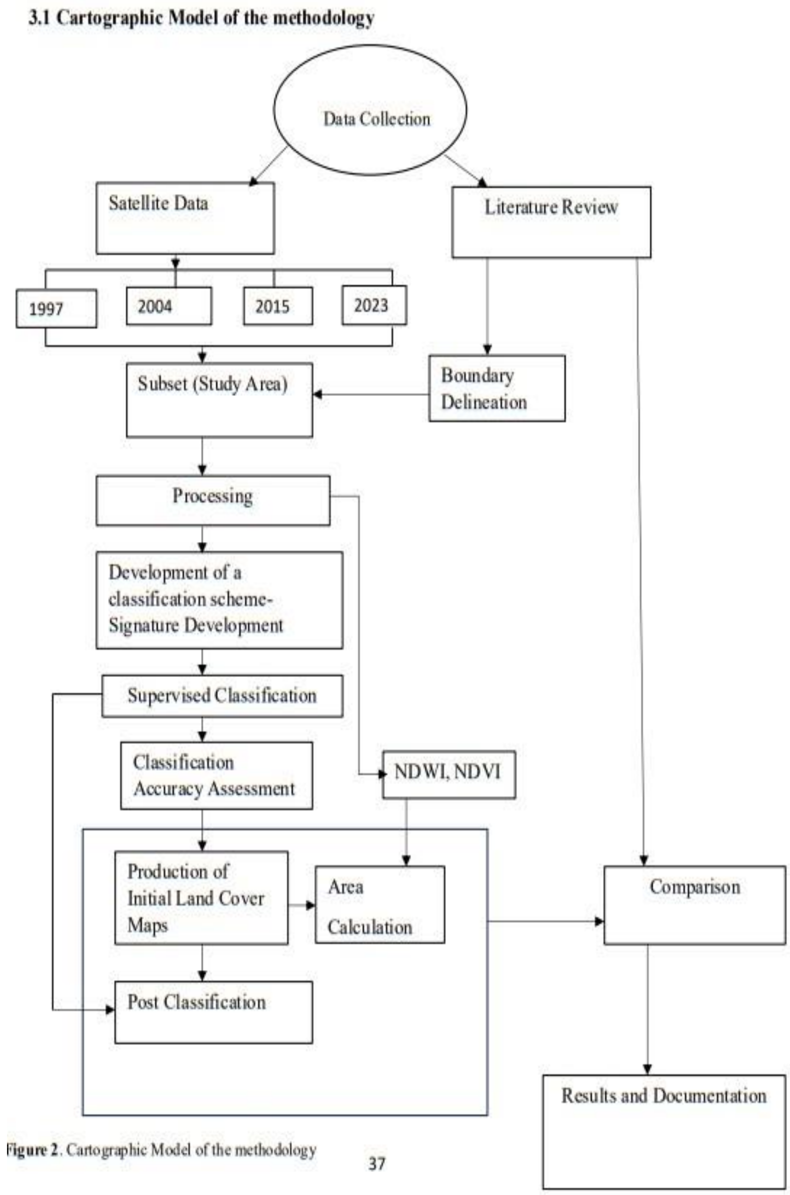


Figure 4: Cartographic model of the methodology

The total analysis was based on transforming ideas into maps and graphs. Temporal Satellite dataset from 1997 to 2023 were analyzed individually. A short generalization was done for proper planning. After the analysis of each satellite data the results were compared to evaluate the study findings. A detail change detection analysis was assessed by implementing pre-and post-change detection techniques. Integration of several techniques identified the critical change areas.

3.6.1 Result evaluation and report writing

The study focuses on the land cover change over a long period (1997–2023) of the study area. So, the overall scientific analysis determined the state, dynamics, and trend of changing landscape of Muthurajawela Marsh-Negombo Lagoon Wetland Complex. Besides the change detection the relation and interaction between various land cover was also assessed. The overall scenario of changing land cover was evaluated with satisfactory precision.

4. Results and discussion

4.1. Preprocessing

4.1.1. Noise reduction

When it comes to atmospheric correction process a manual radiance to reflectance model was constructed to measure TOA (top of atmosphere) reflectance value of each band of the satellite images. Earth sun elevation at the when the image was acquired, the value is collected by the meta data of Each Landsat image bundle of Landsat level 1 data. The value of solar irradiance was summarized for TM, OLI/TIRS sensors using the meta data.

Landsat Collections Level-1 data can be rescaled to top of atmosphere (TOA) reflectance and/or radiance using radiometric rescaling coefficients provided in the metadata file that is delivered with the Level-1 product. The metadata file also contains the thermal constants needed to convert thermal band data to TOA brightness temperature (United States Geodetic Survey, 2023).

Reflective band DN's can be converted to TOA reflectance using the rescaling coefficients in the MTL file:

$$\rho\lambda' = M_\rho Q_{cal} + A_\rho$$

where:

$\boldsymbol{\rho_{\lambda'}}$ = TOA planetary reflectance, without correction for solar angle. Note that $\rho\lambda'$ does not contain a correction for the sun angle.

M_ρ =Band-specific multiplicative rescaling factor from the metadata (REFLECTANCE_MULT_BAND_x, where x is the band number)
A_ρ =Band-specific additive rescaling factor from the metadata (REFLECTANCE_ADD_BAND_x, where x is the band number)
Q_{cal} = Quantized and calibrated standard product pixel values (DN)

TOA reflectance with a correction for the sun angle is then:

$$\rho_\lambda = \frac{\rho_\lambda'}{\cos(\theta_{SZ})} = \frac{\rho_\lambda'}{\sin(\theta_{SE})}$$

where:

ρ_λ= TOA planetary reflectance
θ_{SE} = Local sun elevation angle. The scene center sun elevation angle in degrees is provided in the metadata (SUN_ELEVATION).
θ_{SZ} =Local solar zenith angle; $\theta_{SZ} = 90° - \theta_{SE}$

Conversion from Qcal in Level 1 products back to at-sensor spectral radiance (Lk) requires knowledge of the lower and upper limit of the original rescaling factors (Chander et al., 2009). During radiometric calibration, pixel values (Q) from raw, unprocessed image data were converted to units of absolute spectral radiance using 32-bit floating-point calculations. The absolute radiance values were then scaled to 7-bit (MSS, Qcal max = 255), 8-bit (TM and ETM+, Qcalmax = 255), and 16-bit (ALI, Qcalmax = 32,767) numbers representing Qcal before layout.

4.2 Classification

The Supervised Maximum Likelihood Classification used in this study. It is one of the mostly used method in image data analysis in remote sensing. It identifies and locates land cover types that are known a priori through a combination of personal experience, interpretation of aerial photography, map analysis and field work (Jensen,2005 cited in Haque and Basak, 2017).

It uses the means and variances of the training data to estimate the probability that a pixel is a member of a class. The pixel is then placed in the class with the highest probability of membership (Ozesmi and Bauer, 2002 cited in Haque and Basak, 2017).

The classification scheme was developed for the further analysis of the satellite images based on the characteristics of the study area. Negombo lagoon and Muthurajawela wetland complex is more bounded by water and marshy vegetation.

After developing the signature files for each satellite image of different time slots, the final step of image classification, maximum likelihood parametric rule was applied. Based on statistics (mean; variance), a probability function was calculated from the inputs for classes established from training samples. Each pixel was judged as to the class to which it most probably belongs.

4.3. Accuracy assessment

In this study classification accuracy assessment was conducted with the reference of the raw satellite images. In maximum likelihood classification, often many pixels remain misclassified because of the uneven distribution of data. Classification accuracy should be done by ground truthing, or by physical appearance in the study site. But in this case time is one of the major resistant because we can't measure the past with the present. So, to acquire better accuracy of the classification both infield and outfield accuracy assessment is necessary. In this study outfield assessment was done by random sampling of the reference image. The total process was done by comparing the reference image with the classified image with some random points. Stratified random sampling was adopted to calculate the classification accuracy of each land cover image. The logic to use this sampling method is- each land cover class found equal probability to be observed. 50 Random points were used for accuracy assessment of every classified image. Some observation show ‘‘0” class values, which are neglected. The data is summarized and quantified by using error matrix. Four different accuracy results- user accuracy, producer accuracy, total accuracy, kappa index was produced from the overall assessment which help to understand the accuracy of the classification.

The calculated assessment result of each classified satellite image from 1997 to 2023 was shown from Tables 3–6. Calculated total accuracy result for each satellite image (1997, 2004, 2015, 2023) given as 93.10 %, 94.92 %, 84.13 % and 85.94 % respectively, when calculated kappa statistics results are 0.9129, 0.9356, 0.8021 and 0.8222 respectively derived from Tables 3–6.

Table 3

Accuracy Assessment result of classified image (1997/02/07).

Land Use/Cover category	Classified pixel totals	No. of correct pixels	Producer Accuracy	User Accuracy	Overall Accuracy	Kappa Coefficient
Water	16	15	100 %	93.75 %	93.10 %	0.9129
Vegetation	12	12	80 %	100 %		
Marsh Land	10	9	100 %	90 %		
Built up Area	10	10	90.91 %	100%		
Bare land	10	8	100 %	80 %		

Table 4

Accuracy Assessment result of classified image (2004/02/11).

Land Use/Cover category	Classified pixel totals	No. of correct pixels	Producer Accuracy	User Accuracy	Overall Accuracy	Kappa Coefficient
Water	13	12	92.31 %	92.31 %	94.92 %	0.9356
Vegetation	10	10	90.91 %	100 %		
Marsh Land	10	10	100%	100 %		
Built up Area	16	16	94.12%	100 %		
Bare land	10	8	100 %	80 %		

Table 5

Accuracy Assessment result of classified image (2015/04/14)

Land Use/Cover category	**Classified pixel totals**	**No. of correct pixels**	**Producer Accuracy**	**User Accuracy**	**Overall Accuracy**	**Kappa Coefficient**
Water	14	13	92.86%	92.86%	84.13 %	0.8021
Vegetation	10	10	83.33 %	100 %		
Marsh Land	10	10	100 %	100 %		
Built up Area	12	11	61.11 %	91.67 %		
Bare land	17	9	100 %	52.94 %		

Table 6

Accuracy Assessment result of classified image (2023/04/12)

Land Use/Cover category	Classified pixel totals	No. of correct pixels	Producer Accuracy	User Accuracy	Overall Accuracy	Kappa Coefficient
Water	13	12	70.59 %	92.31 %	85.94 %	0.8222
Vegetation	10	9	75 %	90 %		
Marsh Land	10	10	100 %	100 %		
Built up Area	18	17	94.44 %	94.44 %		
Bare land	13	7	100 %	53.85 %		

The Highest Classification accuracy is found in the 2004 image which was a product of Landsat 5 TM sensor. All other images were the product of Landsat OLI/TIRS sensors. According to the knowledge gathered by these assessments almost all the evaluated results are satisfactory.

When examining the Kappa Coefficient of datasets of 1997,2004,2015 and 2023, almost all the evaluated results respectively 0.9129, 0.9356, 0.8021and 0.8222 are satisfactory as every value is in the range of 0.81-1.00, all the values interpreted as in proper agreement.

4.4 Land cover change detection

There are two broad methods of Change Detection Techniques includes- a) Pre-Classification Method, b) Post Classification Method. Pre-Classification method analyses the change without classifying the image value. The most common and widely used pre-classification method is Vegetation Index Differencing (NDVI). Various index has developed after NDVI e.g. NDWI, MNDWI, Pearson Correlation coefficient analysis; methods to Measure the linear relationship between two variables.

There are many ways to assess post classification of land cover. ENVI thematic change workflow tool was used to portray the dynamics of land cover change changes that occurred in Muthurajawela marsh-Negombo lagoon wetland complex from 1997 to 2023. This particular tool measures the transition dynamics of a land cover class to another land cover class at a given extent.

As there is a temporal comparison, time 1 image and time 2 image are given as input to generate land cover change dynamics. Only changed areas can be taken into the consideration. In this analysis, change dynamics are generated as between two-time spans. It gives a better understanding about which land cover class changes to which land cover class over time.

4.4.1. NDVI analysis

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

The Normalized Difference Vegetation Index (NDVI) measures vegetation health by comparing near-infrared (NIR) light, which vegetation reflects, with red light, which it absorbs. NDVI values range from -1 to +1; higher values indicate healthier vegetation with strong NIR reflectance and low red reflectance, while lower values suggest sparse or absent vegetation. NDVI is a standardized method for assessing vegetation density and health.

In this study, NDVI is used to classify vegetation into categories of high, moderate, and low density. For Landsat TM and ETM, Band 4 represents NIR and Band 3 represents red; for Landsat 8-9, Band 5 is NIR and Band 4 is red.

After successful production of NDVI maps, reclassification was done using Jenks natural breaks algorithm with Maximum Threshold 0.950 used to classify each Vegetation Differentiating Only positive values were taken in count to classify each image. Higher positive values are classified as forested vegetation and values close to zero are classified as mix vegetation which might consist of settlement, water body, or any other land cover feature. All the negative value including zero are classified with default legend and then ignored during presentation. After aerial calculation of classified NDVI images (Fig. 3) linear regression line was constructed for each category (Fig. 4). Time was taken as the independent factor (x) and area was taken as the dependent factor during the calculation.

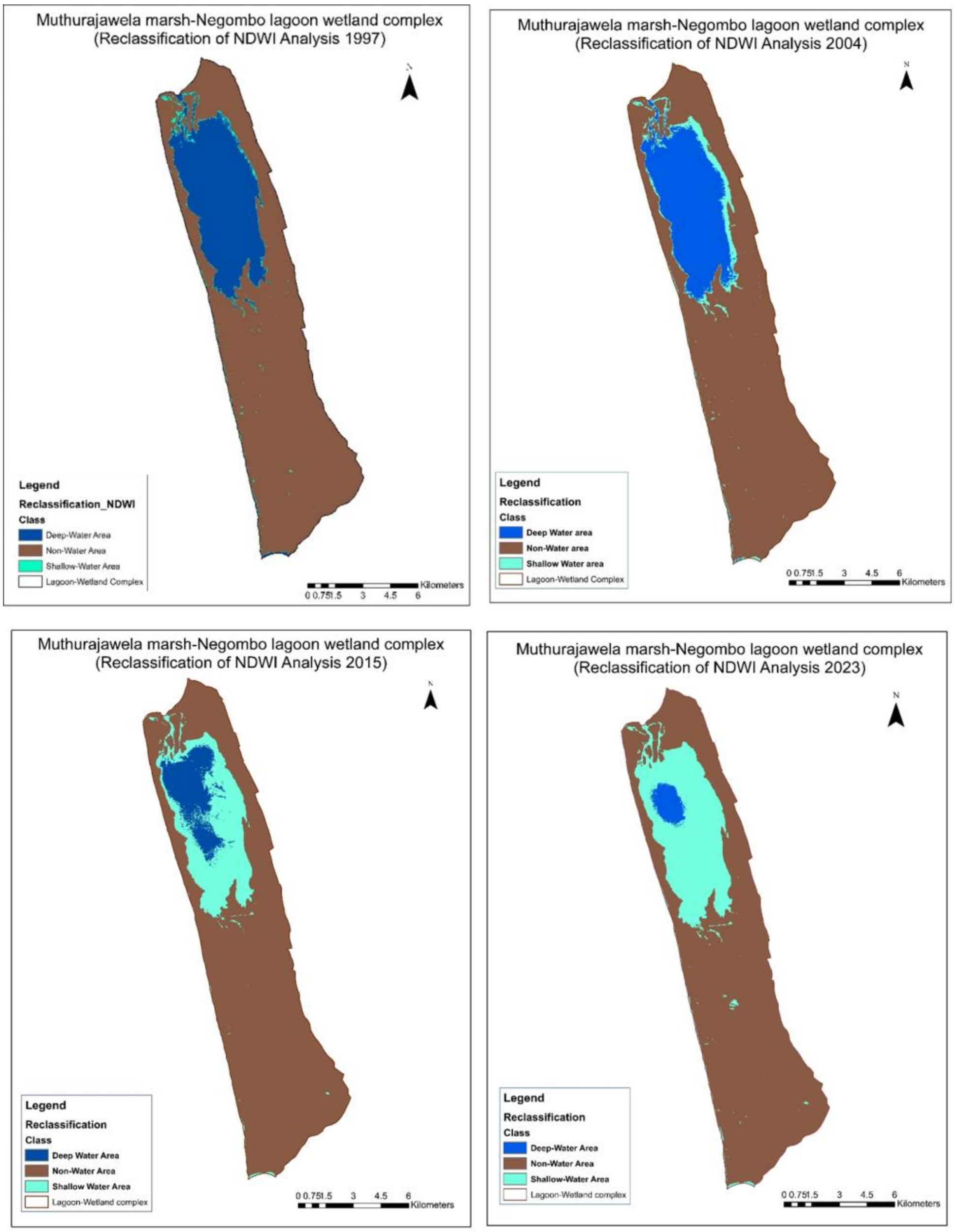
4.4.2. NDWI analysis

$$NDWI = \frac{Green - NIR}{Green + NIR}$$

Demarcated the NDWI analysis result for every respective year from 1980 to 2010. The Grayscale images in the left side shows the NDWI values. Higher values indicate the water extent and lower values demarcate other land covers. In the right side 4 consecutive maps are produced based on the NDWI values. Only higher positive NDWI values are taken to classify two water classes as deep water and shallow water. For Landsat TM and ETM sensors band 2 was regarded as GREEN and Band 4 regarded as NIR. n Landsat 8-9 Operational Land Imager (OLI)/Thermal Infrared Sensor (TIRS) band 5 is regarded as NIR and Band 3 regarded as GREEN.

After classification and aerial calculation, a linear regression (Fig. 6) was implemented which results a downward trend line for the deep-water class when a positive increase found in case of Shallow Water class. Time was taken as the independent factor (x) and Area was taken as the dependent factor during the calculation.

NDWI Analysis (1997-2023)



Coordinate System: Datum: WGS 1984 WGS 1984 UTM Zone 44N, Projection: Transverse Mercator

4.4.3. Quantitative analysis

After calculating the areal context of each land cover class of each supervised classification map, quantitative measurements of urban development in each study area or time period in terms of area covered by urban development can be measured (e.g., square kilometers).

Vegetation Data cover for the same areas and time periods can be derived from the reclassified NDVI maps. This could be in terms of area covered by vegetation (e.g., square kilometers).

Table 7

Land Use/Land Cover Distribution: percentage, areal extent.

LANDUSE /LAND COVER CATEGORIES	1997		2004		2015		2023	
	Area (km)	Area (%)	Area (km)	Area (%)	Area (km)	Area (%)	Area (km)	Area (%)
Water	38.42	32%	31.53	26%	33.60	27%	32.37	26%
Vegetation	30.75	26%	20.24	17%	7.42	6%	7.99	6%
Marsh Land	19.19	15%	13.21	11%	10.28	8%	8.01	6%
Built-up Area	21.16	18%	42.16	35%	30.00	24%	47.91	38%
Bare Land	11.18	9%	13.35	11%	42.64	34%	29.51	23%

When examining the urban development and the vegetation cover of this important wetland complex, it is important to understand the term urban development. Urban development involves the enhancement and expansion of urban areas by improving infrastructure, housing, commercial spaces, and community services to support growing populations and promote economic and social progress (World Bank, 2014).

Vegetation may be defined as the patchwork of plant species arrayed across the landscape. It includes a variety of life forms such as trees, shrubs, grasses, forbs and non-vascular plants like mosses (De Anza College, 2023). Vegetation is the plant life or total plant cover as of an area (Merriam-Webster,2023).

Both built-up area and land clearing (bare land) are considered to measure urban development. As They provide insights into the extent of urbanization, the changes in land use, and the associated environmental impacts. Highland vegetation and marshlands are considered as the whole vegetation.

Table 8

Areal extent of urban area and vegetation

Time period	**Urban area (sqkm)**	**Vegetation (sqkm)**
1997	32.34	49.94
2004	55.46	33.45
2015	72.64	17.7
2023	77.42	16

Correlation Coefficient Analysis

Statistical method to analyze the correlation between urban development and vegetation was used. This was done using Correlation coefficient. Measures the linear relationship between two variables. Therefore,

$$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{[n\Sigma x^2 - (\Sigma x)^2][n\Sigma y^2 - (\Sigma y)^2]}}$$

The correlation coefficient of -0.89 between urban area and vegetation in the Muthurajawela Marsh and Negombo Lagoon indicates a strong negative relationship. This means that as urban area increases, the extent of vegetation tends to decrease significantly.

- 1997 to 2004: The urban area grew from 32.34 sq km to 55.46 sq km, while vegetation decreased from 49.94 sq km to 33.45 sq km. This suggests that urban expansion is associated with a substantial loss of vegetation.
- 2004 to 2015: The urban area continued to increase to 72.64 sq km, but vegetation decreased further to 17.7 sq km. The trend of urbanization contributing to vegetation loss persists.
- 2015 to 2023: Urban area expanded slightly to 77.42 sq km, while vegetation decreased slightly to 16 sq km. The trend of reduced vegetation in the face of increasing urban development continues.

Overall, the negative correlation underscores the impact of urban growth on vegetation loss in the area, highlighting the potential environmental consequences of urban expansion.

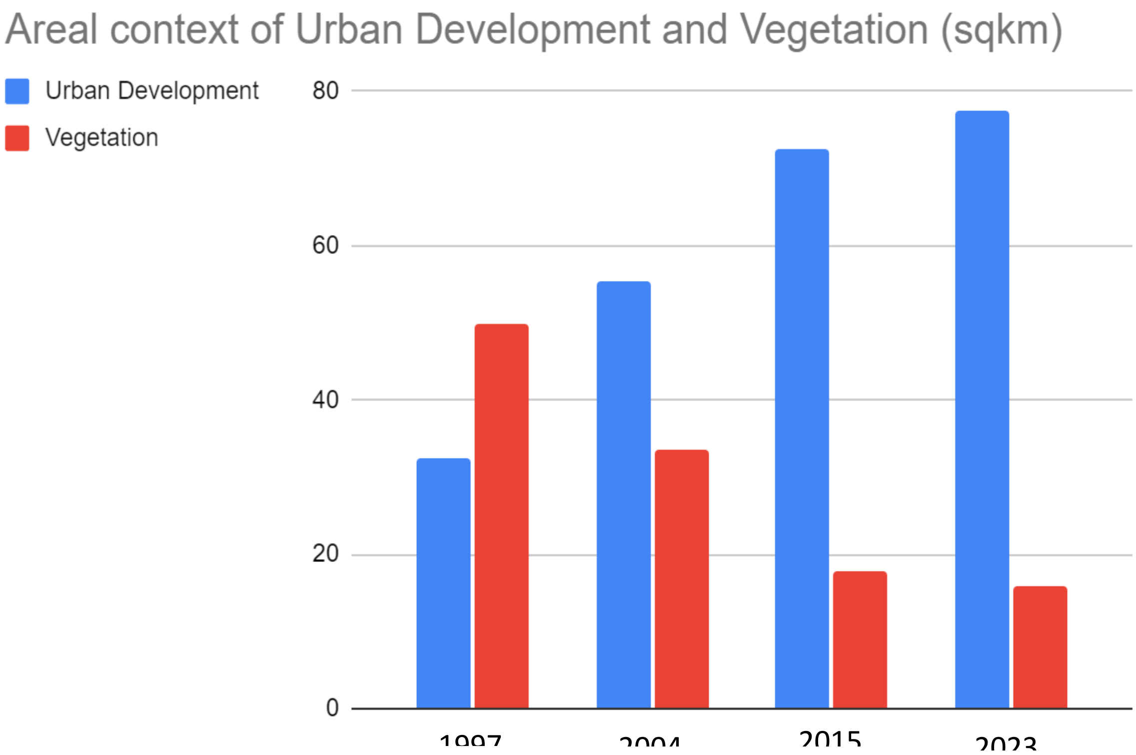
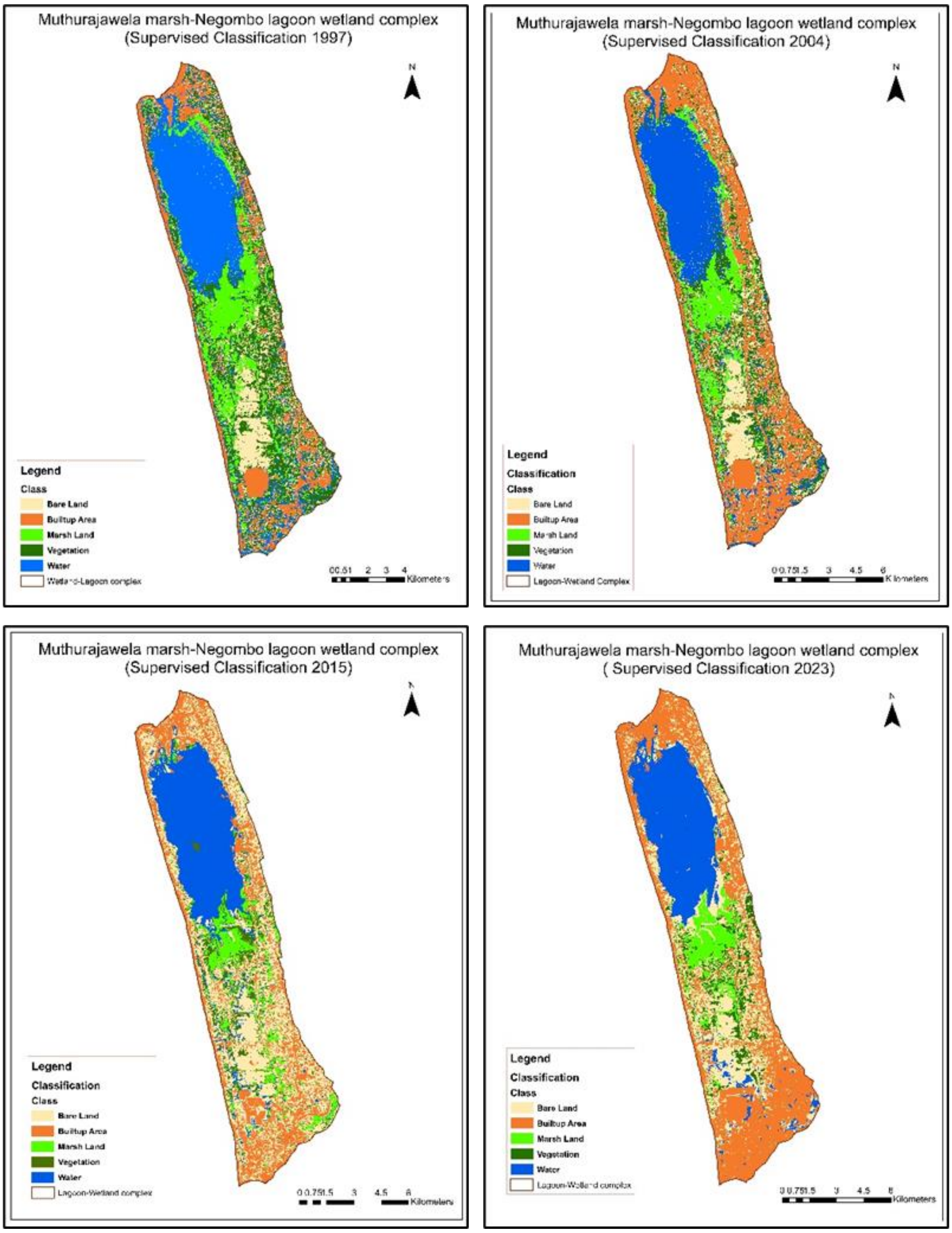


Figure 5: Areal extent of Urban development and Vegetation

Classified Land Cover Maps of Muthurajawela marsh-Negombo lagoon wetland complex (1997-2023)



Coordinate System: Datum: WGS 1984 WGS 1984 UTM Zone 44N Projection: Transverse Mercator

4.4.4. Change Detection Statistics

Urban development involves the enhancement and expansion of urban areas by improving infrastructure, housing, commercial spaces, and community services to support growing populations and promote economic and social progress (World Bank, 2014).

It is an indication of higher vegetation cover as well as huge biodiversity in this coastal wetland complex at that time. Comparing with the vegetation cover and marshy land, built up area seems to be less occupied. Agricultural activities seem to be practiced than development of buildings and other constructions in 1997 scenario. the pattern of land use land cover distribution in 2023 after 26 years has so many changes comparing with the Built-up area occupies a major part of the total land.

Vegetation and Marsh land classes maintain the least position of land cover while built-up occupies the highest position in the land cover extent in 2023. In 2023 bare lands are reduced to 23% to 29.51 km2 areal extent.

There may be a huge conversion of bare land into built up areas due to land development projects, spontaneous settlements. As Vegetation and Marsh land classes maintain the least position of 6% in the classes, there may be condition of deforestation (reduction of forest cover in terms of the extent) is happening in this study area.

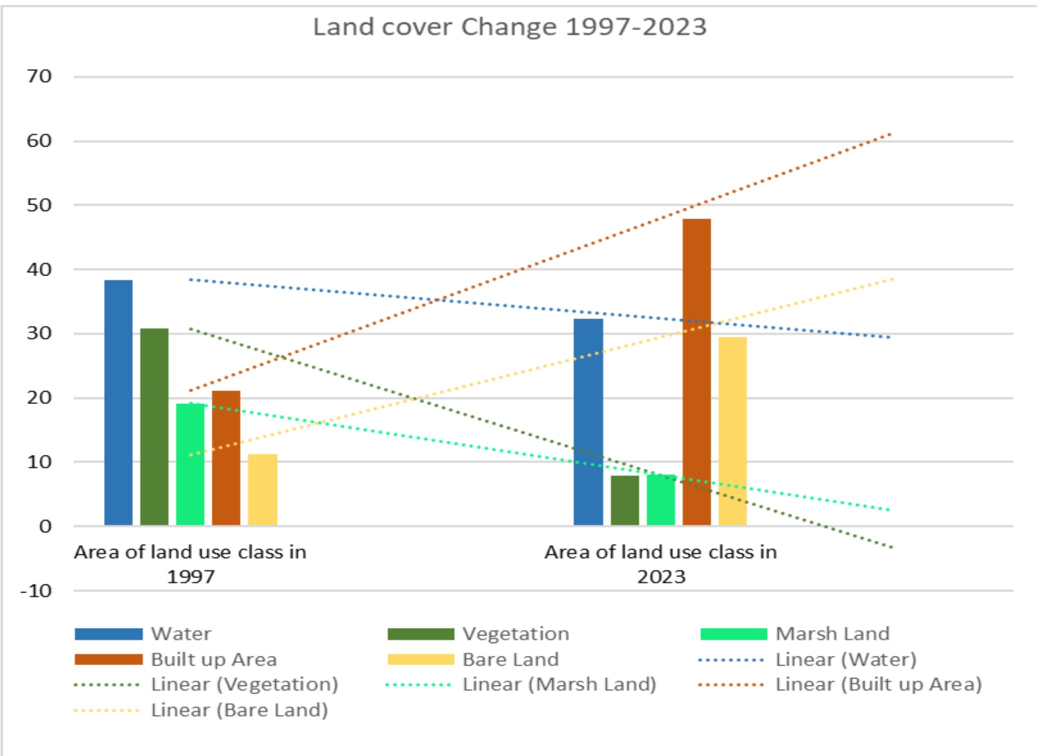


Figure 6: Areal extent of LULC Categories

Vegetation cover shows a trend of rapidly decreasing trendline. Marsh lands also show a decreasing trendline which indicates that marsh lands are vanishing. On the other hand, linear trend of Built-up areas is rapidly increasing. There is a gradual increasement of Bare lands can be identified.

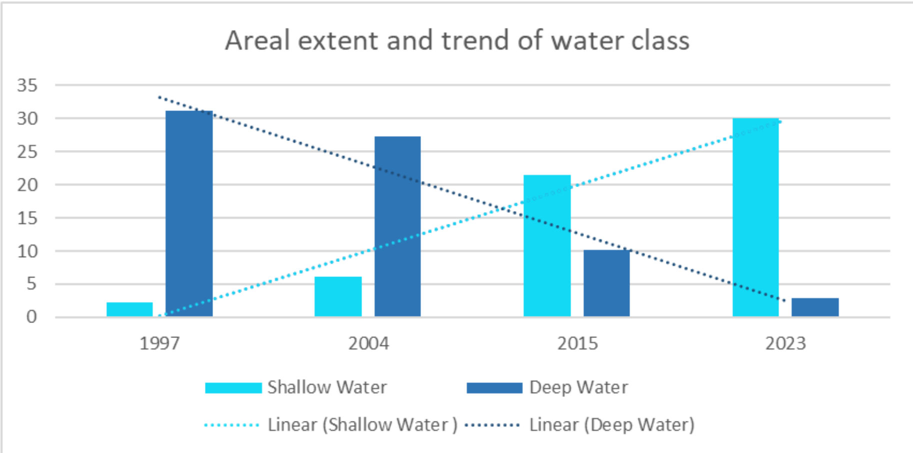


Figure 7: Areal extent of deep and shallow water in Negombo lagoon

The linear trend of Shallow water is rapidly increasing. In contrary, Deep water indicates a decreasing trendline. It interprets that the depth of the Negombo lagoon is rapidly diminishing. According to the above bar graph when examining the linear trend of land cover changers from 1997 to 2023, change of water bodies remain deliberate than other land cover classes.

4.4.5. Thematic Change Dynamics

A convenient way to assess the post classification change dynamics is identifying the thematic change based on change statistics. ENVI thematic change workflow tool was used to portray the dynamics of land cover change that have taken place in Muthurajawela march – Negombo lagoon wetland complex. From 1997 to 2023. The tool measures the transition dynamics of a land cover class to another class at a given extent. Firstly, initial state image was inputted as a time 1st image and final state image as time 2nd Image registration task was skipped as done before during area calculation. Only changed areas were taken to visualize the overall dynamics.

The study only considered the valid classes which carry a significant change resultant. 10 classes were eliminated as they have no valid change or '0' change value to visualize. In accordance with the above table, it demonstrates the land cover conversion from one land cover class to another from 1997-2023. ENVI thematic change workflow tool was used to portray land cover dynamics of Muthurajawela marsh-Negombo lagoon wetland complex.

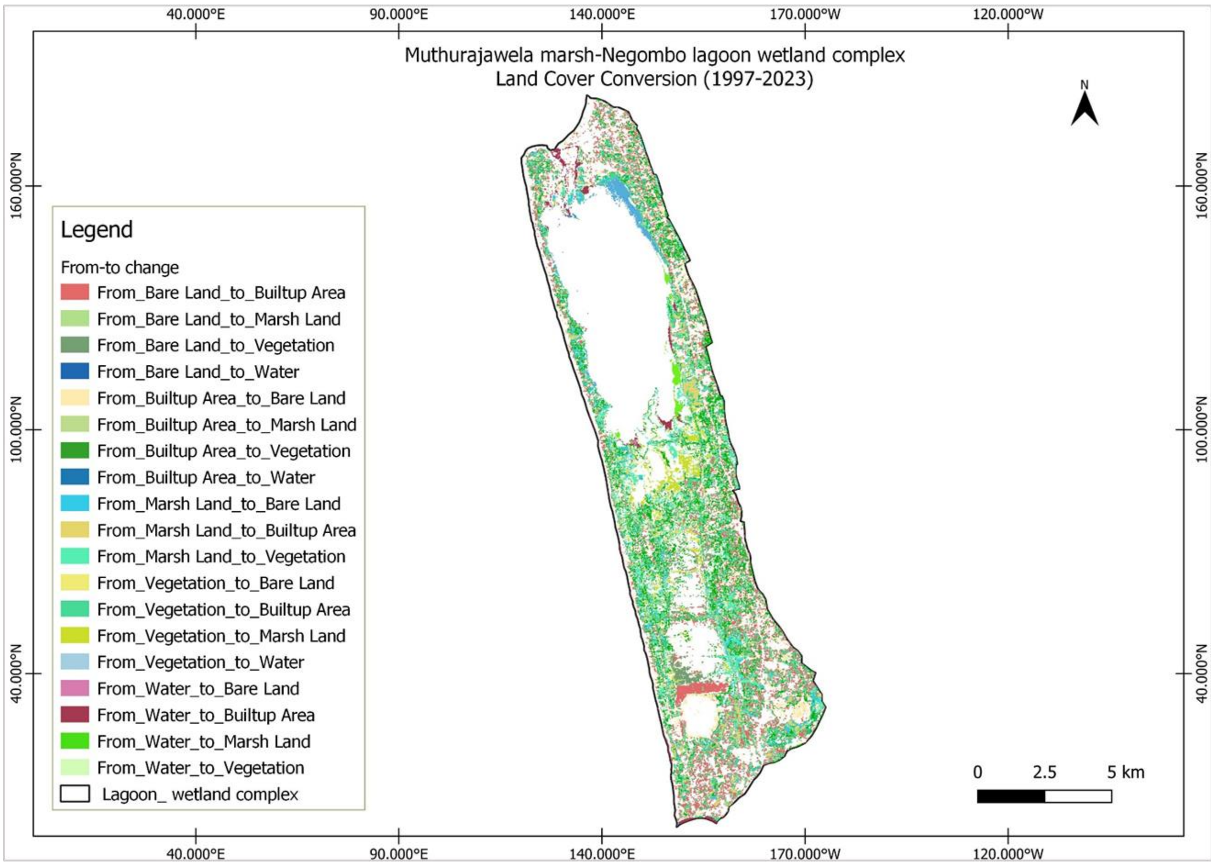


Figure 8: Areal extent of deep and shallow water in Negombo lagoon

1997	2023	Changed area (sq.km)	Percent change
From Bare Land	To built-up Area	11.94	9%
From Bare Land	To Marsh Land	0.36	0.28 %
From Bare Land	To Vegetation	1.83	1.42%
From Bare Land	To Water	0.006	0.005%
From Built-up Area	To Bare Land	2.94	2.29%
From Built-up Area	To Marsh Land	0.02	0.02%
From Built-up Area	To Vegetation	0.25	0.20%
From Built-up Area	To Water	0.07	0.05%
From Marsh Land	To Bare Land	5.35	4.17%
From Marsh Land	To Built-up Area	4.63	3.61%
From Marsh Land	To Vegetation	3.02	2.35%
From no change	To no change	68.86	53.58%
From Vegetation	To Bare Land	12.77	9.93%
From Vegetation	To Built-up Area	11.07	8.61%
From Vegetation	To Marsh Land	2.42	1.88%
From Vegetation	To Water	1.19	0.93%
From Water	To Bare Land	0.04	0.03%
From Water	To Built-up Area	1.16	0.91%
From Water	To Marsh Land	0.0018	0.001%
From Water	To Vegetation	0.57	0.44%

Figure 9: Thematic change statistics: from-to change matrices (1997-2023)

4.4.6. Results and Discussions

Different pre and post classification methods were used in this study for complete identification and in-depth analysis of land cover change. Each method produces different types of results which helps to analyze the complex behavior of land cover feature. Impact of land cover change influence approximately 46% of the total landscape of the study area within 1997 2023. The results shows that 90% extent of deep-water body change its state mostly to shallow water. The NDWI analysis shows around 28.35 km2 of deep-water body has degraded within 1997-2023.

Once Vegetation was a dominant land cover feature of Muthurajawela marsh-Negombo lagoon wetland complex. But within 26 years from 1997 it is decreased more than 20%. Not only that Marsh lands also consists of high biodiversity in the study area. As Negombo lagoon is a great ecosystem for marshy vegetation, Marsh lands occupy 15% of land area from the entire areal extent in 1997. But marsh lands are less than 10% in 2023. Thematic change analysis shows that most of vegetation cover is converted into bare lands and built-up areas.

Thematic change analysis also highlights that most of marsh lands are converted into bare lands and built-up areas. The acceleration of degradation in Marsh lands and vegetation was maximum within 1997-2023, When the most forested land was transferred to semi emergent crop land. Not only forests marsh lands also converted to areas where lot of land development projects are conducted.

Increasement in built up areas is an indication of an increasing population. Population pressure and insufficient land is the main cause of urban expansion in the sense of the expansion of built-up areas. As Built-up areas occupy almost 40 % of the total land extent there must be rapid increasement in settlements.

Greater Colombo Economic Commission highlighted in 1991 that Current small scale land reclamation by local fishermen communities on the islands in the mouth of the Negombo lagoon is a threat to water flow between the sea and the lagoon and Degradation in the lagoon in: the water depth, particularly in the shore regions

The thematic change workflow effectively illustrated the dynamics of land cover changes over various time periods. A key component, the transition probability matrix, provided a detailed comparison of past and present land cover states, demonstrating the typical behavior of each land cover type through change dynamics. Integrating these techniques allowed for a comprehensive understanding of the extent, condition, direction, and patterns of land cover change.

The analysis results, covering 1980 to 2010, are summarized in the following change matrices: Thematic Change analysis revealed that 46% of the total land cover in the Muthurajawela Wetland has shifted over the past 30 years. From 1997 to 2023, the area experienced significant ecological transformations. While the water areas of Negombo Lagoon remained stable at 26-32%, 90% of deep-water zones have transitioned to shallow waters, suggesting a shoaling process that impacts water quality and habitats.

Highland vegetation, including agriculture and forests, saw a dramatic decline from 26% to 6% by 2015 and 2023, indicating substantial loss due to urban expansion. Similarly, marshland decreased consistently from 15% to 6%, reflecting ongoing challenges in wetland conservation and prawn farming.

Built-up areas increased significantly from 18% to 38%, highlighting the rapid expansion of urban development and its impact on natural landscapes. Concurrently, bare land decreased from 34% in 2015 to 23% in 2023, likely due to changes in land management or reclamation efforts.

Key changes include the notable conversion of marshland to bare land, totaling 5.35 sq km (4.17%), and substantial urban development, which converted 11.94 sq km (9%) from bare land to built-up areas. These findings underscore the trend toward urbanization, ecological shifts affecting biodiversity, and the urgent need for sustainable land management to preserve the Muthurajawela Marsh-Negombo Lagoon Wetland Complex.

5.Conclusion

Land cover changes have affected approximately 46% of the study area's landscape between 1997 and 2023. The analysis reveals that anthropogenic factors are the primary drivers of these changes. Specifically, 90% of deep-water bodies have predominantly transitioned to shallow water. NDWI analysis indicates that about 30.04 square kilometers of deep water have degraded between 1997 and 2023. Additionally, local reports suggest that suggesting a shoaling process that impacts water quality and habitats and prevalent prawn farming accelerating the degradation of deep-water areas.

The vegetation cover, once the second most prevalent land cover type in Muthurajawela marsh-Negombo lagoon wetland complex, has decreased by over 20% over the past 30 years since 1997. The transition matrix indicates that forested land has largely been converted to either bare lands or built areas. NDVI analysis provides a more detailed view, showing that approximately 22.76 square kilometers of forested land has degraded over this period.

- The period **2004-2015** shows the highest percentage decrease in vegetation (47.1%), indicating the most rapid degradation.
- The period **1997-2004** also shows significant degradation (32.9%), but less severe than 2004-2015.
- The period **2015-2023** shows the least change in vegetation area (9.6%). The rise in crop cultivation and the subsequent expansion of settlements are major factors driving the significant loss of forested areas.

In conclusion, almost 50 % of the land has been changed over three decades. if people are aware of the high biodiversity of Muthurajawela marsh-Negombo lagoon wetland complex and how to consume and deal with natural features and vegetation cover especially littoral vegetation such as mangroves, the degradation vegetation cover and marsh land can be reduced.

Rapid development of land is very useful for the advancement of residents in the study area. Development and expansion of built-up areas would be great if integrated conservation plan of natural resources is combined with it. If people can learn how to consume things while living, the natural balance of will be restored and development projects and constructions can be done sustainably.

The results and resolution suggested of this research can be a powerful component for further investigations. This study emphasizes the need for sustainable practices including eco-friendly cultivation and developments to mitigate wetland degradation.

References

Merriam-Webster. (n.d.). Semantics. In Merriam-Webster.com dictionary. Retrieved January 4, 2020, from https://www.merriam-webster.com/dictionary/semantics

Wang, S.W, Gebru, B.M, Lamchin, M. (2020). Land Use and Land Cover Change Detection and Prediction in the Kathmandu District of Nepal Using Remote Sensing and GIS. MDPI. (online). Available from: https://www.mdpi.com/2071-1050/12/9/3925

Greater Colombo Economic Commission (1991). The Master Plan of Muthurajawela Marsh and Negombo Lagoon. (online). Gunaratne Offset Limited. Available from: https://portals.iucn.org/library/node/22068

Lakpura LLC. (2022). Muthurajawela Wetlands. (online). Available from: https://lk.lakpura.com/pages/muthurajawela-wetlands?shpxid=8363141e-0a17-400e 91fc58d4dc309174

European Environment Agency. (2022). land cover. (online). European Environment Agency. Available from: https://www.eea.europa.eu/help/glossary/eea-glossary/land-cover

United States Geological Survey. (n.d.). *Remote Sensing; U.S. Geological Survey*. (online). Available from: https://www.usgs.gov/centers/california-water-science-center/science/sciencetopics/remote sensing

Esri. (2023). What is GIS? | Geographic Information System Mapping Technology. (online). Available from: https://www.esri.in/en-in/what-is-gis/overview

Haque, I. Basak, R. (2017). Land cover change detection using GIS and remote sensing techniques: A Spatio-temporal study on Tanguar Haor. Sunamganj, Bangladesh. Elsevier. (online) Available from: https://www.sciencedirect.com/science/article/pii/S1110982316301533

Chamara, S. (2021). The Legal Quagmire over the Muthurajawela marshlands. the morning, (online)p.5.Available from: https://www.bing.com/ck/a?!&&p=c04a3168f4fac54cJmltdHM9MTY3MjM1ODQwMCZpZ3VpZD0wYjEyOTg4Ni01OTIyLTY0NTgtMDg3ZC04OGVmNWQyMjZhMzcmaW5zaWQ9NTE1NA&ptn=3&hsh=3&fclid=0b129886-5922-6458 087d88ef5d226a37&psq=The+Legal+Quagmire+over+the+Muthurajawela+marshlads&u=a1aHR0cHM6Ly93d3cudGhlbW9ybmluZy5say90aGUtbGVnYWwtcXVhZ21pcmUtb3Zlci10aGUtbXV0aHVyYWphd2VsYS1tYXJzaGxhbmRzLw&ntb=1

Kirinde, C., (2018). How public-spirited residents stopped the rape of Muthurajawela Sanctuary.

The Sunday Times, p.8.