ASSESING WETLAND DEGRADATION USING MULTI-TEMPORAL REMOTE SENSING DATA

A case of Usangu Wetland

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A Dissertation submitted to the Department of Geospatial Sciences and Technology in Partial Fulfilment of the Requirements for the Award of Bachelor of Science in Geographic Information Systems and Remote Sensing (GIS & RS) of Ardhi University.

CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by Ardhi university of a dissertation titled **"Assessing wetland degradation using multi-temporal remote sensing data, a case study of Usangu wetland"** in Partial Fulfilment of the Requirements for the Award of degree of Bachelor of Science in Geographic for University Examination.

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DECLARATION AND COPYRIGHT

I, JOEL ZABLON NYITTI declare that the contents of this dissertation are the results of my own findings through my study and investigation and that to the best of my knowledge, they have not been presented anywhere else as a dissertation for diploma, degree or any similar academic award in any institution of higher learning.

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JOEL ZABLON NYITTI

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This research is dedicated to my loving parents, Zablon Nyitti and Eliafile Nassary whose unwavering support and encouragement have been the driving force behind my academic journey. Your belief in me and constant motivation have been instrumental in reaching this milestone.

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ABSTRACT

Wetlands are essential ecosystems, providing crucial environmental benefits and supporting diverse life forms. They are essential for maintaining environmental quality and sustaining livelihoods, especially in Africa where millions of people rely on them for the ecological services they provide. However, their alarming global disappearance calls for urgent attention. This study focuses on the Usangu wetland in southwest Tanzania, which plays a vital role in the ecological landscape and local livelihoods. This research focuses on analyzing Usangu wetland degradation through multi-temporal remote sensing data. The study aims to generate a 2022 landcover map, compute NDVI and NDWI indices from 2013 to 2022, and analyze the factors impacting wetland degradation

In this study, a Geographic Information System (GIS) Weighted analysis is utilized to analyze the contributing factors of degradation, along with an examination of landcover patterns. The study recognizes indices such as NDVI, NDWI, topographical factors and climatic factors such as rainfall as the main the main indicators of the wetland degradation.

The findings of this study reveal that the wetland's degradation status is predominantly characterized by moderate degradation, accounting for the largest proportion of the area at approximately 38.08%. This is followed by regions exhibiting high degradation covering 29.11% and areas with no degradation encompassing 18.52%. Moreover, sections demonstrating low degradation constitute 11.93% of the wetland, while the smallest segment, amounting to 2.35%, displays the highest level of degradation. This comprehensive understanding of wetland degradation dynamics significantly advances our insight into the phenomenon, thereby enabling the formulation of more effective conservation strategies.

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LIST OF ABBREVIATIONS

NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
TWI	Topographic wetness Index
GIS	Geographic Information System
RS	Remote Sensing
GEE	Google Earth Engine
USGS	United States Geological Survey
DOS	Dark Object Subtraction
ATCOR	Atmospheric and Topographic Correction
SRTM	Shuttle Radar Topography Mission
SWIR	Shortwave Infrared
NIR	Near-Infrared
DEM	Digital Elevation Model
TM	Thematic Mapper
ETM+	Enhanced Thematic Mapper Plus
OLI	Operational Land Imager

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Wetlands are crucial ecosystems that provide significant environmental benefits and support diverse forms of life (Schlesinger & Bernhardt, 2013). They are essential for maintaining environmental quality and sustaining livelihoods, especially in Africa where millions of people rely on them for the ecological services they provide. (Kashaigili et al., 2009). Wetlands are vital ecosystems that have earned the nickname "kidneys of the earth" due to their ability to perform multiple ecological functions. They can purify the atmosphere, store and recharge groundwater, improve water quality, regulate floodwaters, protect shorelines, and provide habitats for a number of wildlife species. They are among the most productive ecosystems and harbor a rich biodiversity, while also playing a significant role in carbon sequestration. The wetland ecosystem includes both natural water bodies such as rivers, lakes, coastal lagoons, mangroves, peatlands, and coral reefs, as well as man-made wetlands such as ponds, farm ponds, irrigated fields, sacred groves, salt pans, reservoirs, gravel pits, sewage farms, and canals, as defined by the Ramsar Convention (Karmakar & Bej, 2021).

Wetlands, despite covering only 6% of the Earth's surface, are experiencing alarming rates of disappearance globally (Mkonda, 2022).These ecosystems are increasingly recognized for their significance worldwide. However, many countries face the challenge of lacking accurate records to document changes in wetland distribution, this limitation hinders the development of effective management, protection, and intervention strategies (Kashaigili et al., 2009). Nevertheless, by analyzing the spatial changes in wetland distribution over time, it becomes possible acquire important information that can be used to reconstruct and restore these valuable ecosystems. Therefore, examining the dynamics of wetland distribution provides crucial insights that can contribute to the conservation and sustainable management of these natural systems.

Currently, field survey is the key method used to study wetlands, offering detailed insights into its present conditions. However, due to their resource-intensive nature and limitations in covering large areas comprehensively, field surveys might not suffice for timely monitoring and modeling of future wetland dynamics, particularly those that unfold gradually or seasonally. Therefore, the integration of remote sensing and GIS is crucial to overcome these limitations, enabling a more comprehensive and efficient understanding of the wetland's changes over time and facilitating the development of informed conservation strategies.

The Usangu Basin in southwest Tanzania contains a significant wetland of both seasonal grasslands and a permanent swamp, covering around 20,800 square kilometers and serving as the upper catchment for Tanzania's largest river, the Rufiji. This wetland holds ecological importance and directly impacts the livelihoods of over 200,000 residents. Situated within the Usangu Basin, the Usangu wetland is vital to the Rufiji River and Ruaha National Park, contributing to the park's ecosystem and wildlife habitat. Studying the Usangu wetland offers insights into the interconnectedness of the wetland, the Rufiji River, and Ruaha National Park, which is crucial for conservation strategies aimed at preserving these essential natural resources.

In a similar study carried out in Ghana by (Duku et al., 2022) to investigate Assessment of wetland ecosystem services and human wellbeing nexus, these studies relied heavily on a quantitative approach that combined field surveys and questionnaires. However, this method failed to address the challenges of capturing temporal variations and future dynamics of wetland ecosystems. This underscores the importance of integrating methods like remote sensing and GIS to bridge the gap between detailed field data and a broader understanding of wetland evolution over time.

Also, the Usangu Wetland is a vital component of the Ruaha-Rungwa ecosystem, with far-reaching impacts on ecosystems even thousands of kilometers away. It boasts unique features and, when in a healthy state, supports a remarkable diversity of species. The wetland is home to herds of roan and sable antelopes, while wild dogs roam freely along its rivers. Unusual gatherings of hundreds of ostriches can be observed, and countless migratory bird species pass through. Although some efforts have been made to protect the Usangu Wetland, including its inclusion in Ruaha National Park in 2006, it still faces challenges, such as periods of drought during the dry months. Mismanaged water usage for extensive rice farming has depleted the wetland, resulting in gradually decreasing water levels each year.

1.2 Statement of Research Problem

The existing knowledge about the highland wetlands in the Usangu Catchment is severely limited Given the expansion of highland cultivation and irrigation, coupled with the influence of climatic factors, these wetlands are likely to face significant changes. Addressing the potential impact of both landcover changes and climatic factors on these wetlands has become an urgent imperative. In this context, the application of remote sensing emerges as a promising solution. It offers a comprehensive, up-to-date, and archived information source that spans different time periods, enabling the assessment of shifts in wetland areas. This study aims to utilize Remote Sensing data to evaluate the degradation of the Usangu wetland, considering the combined impacts of landcover changes and climatic factors. By doing so, this research can contribute to a better understanding of the current degradation extent on the Usangu wetland, facilitating their conservation, restoration, and sustainable management.

1.3 Objectives of the study

1.3.1 Main Objective

- To analyze Usangu wetland degradation using multi-temporal remote sensing data

1.3.2 Specific Objectives

- To generate landcover map within the study area using satellite imagery for the year 2022.
- To calculate NDVI and NDWI indices from satellite images spanning the period of 2013-2022.
- To identify and rank the factors influencing the degradation of the wetland from 2013-2022 and produce a wetland degradation map.

1.4 Research Questions

- How can landcover be used to show the current state of the wetland?
- How can NDVI and NDWI remote sensing indices be to analyze changes in vegetation and water content over time?
- What are the contributing factors responsible for the degradation of Usangu wetland?

1.5 Rationale of the Study

The significance of the research lies in its potential to provide accurate and timely information on the spatial and temporal changes of the Usangu wetlands, which are crucial ecosystems for the livelihoods of millions of people in Tanzania. The study's use of remote sensing and satellite imagery offers a cost-effective, repeatable, and up-to-date method for monitoring wetland changes and analyzing the impacts of human activities on these natural systems. The results of this study could help inform the development of effective management, conservation, and intervention strategies to protect these valuable ecosystems, which provide numerous ecological services such as water purification, groundwater recharge, flood regulation, shoreline protection, and biodiversity conservation. Additionally, the study's findings could contribute to the understanding of the impacts of climate change on wetland ecosystems, which have been experiencing alarming rates of disappearance worldwide

1.6 Beneficiaries of the Research.

i. Researchers and Academicians

The outcomes of this study will enable future researchers to use this study as a starting point for their own research, resulting in improved methodology or better strategies for generating better research results.

ii. Policy makers

Policy makers can use the information obtained from this research to develop and implement effective conservation and management policies to protect and restore wetlands.

iii. Local communities

The information obtained from this research can help increase awareness by highlighting the importance and value of wetlands, this research can raise awareness among local communities and encourage them to take an active role in protecting these ecosystems

iv. Government

The government can use the information obtained from this research to make informed decisions about land use planning, such as protecting wetlands from development or promoting sustainable land use practices.

1.7 Scope and Limitations of the Research

The scope of the research is focused on the Usangu wetlands in the Usangu Catchment, Tanzania. The study aims to analyze the degradation of the wetlands over time using remote sensing and satellite imagery, and to detect changes in wetland areas using remote sensing indices. The research integrates the topographic information, meteorological data and remote sensing indices that appears potential in the identification of the degradation of wetland areas hence the study is limited to remote sensing data and satellite imagery, which may not provide a complete picture of the wetlands. Additionally, the study does not include ground-based measurements, which may provide more detailed information on the wetlands. However, this study cannot conclusively establish cause-effect relationships; it can certainly provide a focus on the few factors chosen to determine the extent of degradation, but in reality, degradation is caused by a variety of factors.

1.8 Dissertation Structure

Chapter 1

This chapter introduces the research, presenting background information relevant to the study. It highlights the statement of the problem, discussing the key factors that influence the research focus. The main and specific objectives of the study are outlined, providing an overview of the expected research outcomes. The significance of the research, beneficiaries, and the scope and limitations of the study are also discussed.

Chapter 2

In this chapter, a comprehensive review of relevant literature is conducted, focusing on topics such as wetland dynamics, climate change impacts, and land cover mapping techniques. The chapter provides a succinct summary of previous studies that have explored similar research approaches and methodologies. It synthesizes information from various sources to establish the theoretical and conceptual framework for the research.

Chapter 3

This chapter details the methodology employed to achieve the research objectives. It includes a flowchart illustrating the step-by-step process followed in the study. The methods for data collection and processing are thoroughly described, outlining the specific tools and techniques utilized. This chapter also discusses the criteria used for selecting and analyzing the variables and the rationale behind the chosen methods.

Chapter 4

This chapter presents the results of the research and provides a detailed analysis of the findings. It includes maps and graphs to visually represent and interpret the data. The chapter explores the relationships and patterns observed among the variables, drawing conclusions based on the analysis. It also discusses any limitations or challenges encountered during the data analysis process.

Chapter 5

The final chapter summarizes the key findings of the research and draws conclusions based on the research objectives. It discusses the implications of the findings and their relevance to the broader field of wetland assessment. Additionally, this chapter provides recommendations for future studies or actions based on the research outcomes. These recommendations aim to contribute to the understanding and management of wetland degradation, suggesting potential strategies for conservation and sustainable wetland management.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter presents an overview of existing literature pertaining to the degradation of the Usangu wetland, highlighting its implications for the ecosystem, and the socio-economic well-being of the region.

2.2 Wetlands in Tanzania

Tanzania is very rich in wetland resources which include the Great Lake systems. major river networks and deltaic mangroves. The major lakes and floodplains have long provided a fertile resource base as they include alluvial plains of great agricultural potential. Wetlands in Tanzania support an extensive trading and transport system, fishing grounds, agro-pastoral activities, hydrological processes and, more recently, the harnessing of the river flows for irrigation and hydroelectric power (Kamukala, 2023).

As wetland systems are developed, multiple values inherent in these systems are either ignored or underestimated during their planning in favor of a single interest or sector (Kamukala, 2023). With blind sight, there is increasing awareness not only of the free benefits accruing from intact wetland systems but also of the social, environmental and socio-economic costs of disruption of those systems. Degradation and loss of natural systems can increase the already intense pressures on rural communities.

2.2.1 Laws governing Wetlands

If a wetland is within a national park or game reserve, then its management falls under the control of the Director of Wildlife. Hydropower dams are controlled by the Tanzanian Electricity Company (TANESCO) (Materu et al., 2018). In some areas, for example the Bahi Swamps, the wildlife is under the control of the Director of Wildlife but the wetland is managed by the villagers. The Environmental Management Act, 2004 provides the legal framework for environmental management in Tanzania, including the conservation and protection of wetlands. It establishes the National Environmental Management Council (NEMC) as the main regulatory body responsible for overseeing environmental matters, including wetland management(United Republic of Tanzania, 2004).

2.2.2 Economic value of wildlife in Wetlands

Wetlands provide people with a source of food and skins. Local people hunt for food while the tourist from abroad hunts for trophies, such as skins, horns and ivory. In some areas, illegal hunting has caused wildlife numbers to decline and the Government of Tanzania has neither the finance nor the manpower to control it. The international community has provided funds to assist Tanzania to manage its wildlife. Also, NGOs such as the World Wildlife Fund (WWF), the African Wildlife Fund (AWF), the World Conservation Union (IUCN), German Technical Assistance and individuals have been involved in wildlife conservation and management in Tanzania(Bergin, n.d.).

2.2.3 Usangu Wetland perspective

Water is the most contested resource and the principle determinant of wetland health in Usangu. And because the Usangu Catchment's ecosystem services are essentially hydrological, it is logical that its state be measured through water (Baur et al., 2000). Water and greenness from soil moisture are therefore used as indicators of the extent of wetland and health of the wetland. The Usangu Wetland relies on water inputs from the surrounding catchment area, which are influenced by climate patterns. Changes in precipitation patterns, including prolonged droughts and shifts in rainfall intensity, have led to reduced water availability in the wetland (Benedict, 2019). This water scarcity has resulted in the shrinking of wetland areas, decreased water levels, and altered hydrological processes. These changes have negatively impacted wetland vegetation, wildlife habitats, and the overall functioning of the ecosystem.

2.2.4 Importance of Wetland Conservation

Wetlands provide essential ecological services, such as water purification, flood regulation, and habitat for diverse species (Davidson et al., 2018). The loss and degradation of wetlands have significant ecological, economic, and social implications. The conservation of Usangu Wetland is of utmost importance due to several reasons:

i. **Biodiversity Preservation**

Usangu Wetland harbors a rich and diverse array of plant and animal species. It serves as a habitat for numerous endemic and migratory bird species, aquatic organisms, and unique plant communities. By conserving Usangu Wetland, we can protect this biodiversity hotspot and ensure the survival of many threatened and endangered species.

ii. Water Quality Improvement

The wetland acts as a natural filtration system, purifying water by trapping sediments, nutrients, and pollutants. It plays a vital role in improving water quality by removing contaminants and excess nutrients that may otherwise cause eutrophication and harm aquatic ecosystems. Conserving Usangu Wetland ensures the provision of clean water for both human consumption and aquatic life.

iii. Climate Change Mitigation

Wetlands are effective carbon sinks, capable of sequestering significant amounts of carbon dioxide from the atmosphere. Usangu Wetland's vegetation and soils store substantial carbon, contributing to the mitigation of climate change. Conserving the wetland helps in preserving this carbon stock and reducing greenhouse gas emissions

2.3 Remote Sensing

Remote sensing refers to the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Congalton, 2015).

Remote sensing information including derived vegetation indices and biophysical outcomes have vital preferences, especially high temporal resolution of measurements, wide scope and simple accessibility, for observing and evaluating temporal patterns of natural landscapes and land environments. As a fundamental source of multi-temporal analyses of the land surface, satellite information (especially Landsat Imageries) has been used by several researchers to monitor crucial biological community and land surface properties, map land cover patterns and examine their differences (Orimoloye et al., 2020)

With advancements in remote sensing technologies and analysis techniques, it is anticipated that remote sensing-based assessments will play a crucial role in providing accurate up-to-date information on wetland conditions and in the assessment and monitoring of wetland degradation. Remote sensing provides valuable information about wetland characteristics, changes in land cover, and associated environmental factors. By utilizing satellite imagery, remote sensing indices, and other techniques, researchers can gain insights into the spatial and temporal dynamics of wetlands. It provides a valuable tool for assessing wetland health, detecting degradation processes, and supporting conservation and management efforts(Das et al., 2020).

2.4 Image Classification

Image classification in remote sensing is the process of assigning pixels to nominal which results to the thematic classes (Guo et al., 2017a). The principle of image classification is that a pixel is assigned to a class based on its feature vector by comparing it to the predefined clusters in the feature space where by doing so all image pixels results in a classified image. Spectral pattern is a set of radiance measurements from various wavelength bands for each pixel. Spectral pattern recognition uses pixel by pixel spectral basis for automated classification. Classification procedures can be based on spectral pattern recognition, spatial pattern recognition, temporal pattern recognition (Weih & Riggan, 2008)

2.4.1 Classification Scheme

A classification scheme refers to the system or framework used to categorize and assign labels to different land cover or land use classes within an image (Al-doski et al., 2013). It defines the classes or categories that will be used to represent different features or objects in the image. The classification scheme determines the level of detail and the specific classes that will be targeted during the classification process. The classification scheme can be hierarchical or non-hierarchical, depending on the desired level of detail and complexity.

i. Supervised Classification.

Numerous studies have employed the method of supervised classification when undertaking land cover mapping. Supervised classification involves training a classification algorithm using labeled training data, which represents different land cover classes (Weih & Riggan, 2008). The algorithm learns the spectral patterns associated with each class based on the training data and applies this learned knowledge to classify unlabeled pixels in the image. By assigning class labels to each pixel based on their spectral characteristics, a land cover map can be generated (Al-doski et al., 2013).

ii. Unsupervised classification

In this approach the algorithm groups pixels or data points in an image into clusters based on their spectral characteristics, without prior knowledge or labeled training data (Weih & Riggan, 2008). The algorithm identifies clusters or patterns in the data and assigns class labels to them. However, without the use of reference data or training samples, the resulting classes may not necessarily correspond to meaningful land cover categories(Karmakar & Bej, 2021). The complex and heterogeneous nature of wetland ecosystems, along with the diversity of wetland types and subtypes, make it challenging for unsupervised classification algorithms to accurately capture the specific characteristics of wetlands. Wetlands often exhibit similar spectral signatures to other land cover types such as water bodies, vegetation, or bare soil, making it difficult for unsupervised algorithms to differentiate them effectively.

2.4.2 Random Forest

The random forest algorithm is an ensemble learning method used for classification tasks. It combines multiple decision trees that are trained on randomly selected subsets of the training data and features (Fu et al., 2007).Each decision tree independently classifies new data samples, and the final prediction is determined through majority voting.

The algorithm is robust to noise, captures nonlinear relationships, provides variable importance measures, and can handle high-dimensional data. In wetland studies, random forest has been applied for wetland mapping, wetland type classification, change detection, and assessing wetland health and degradation using remotely sensed data. The random forest algorithm can be trained on multi-temporal data, allowing for the integration of temporal information into the classification process. Additionally, the algorithm's robustness to noise and outliers makes it suitable for dealing with the inherent variability and uncertainty associated with wetland data.

2.5 Remote Sensing Indices

2.5.1 Normalized Difference Vegetation Index (NDVI)

NDVI, or Normalized Difference Vegetation Index, is a widely used remote sensing index to assess vegetation health and monitor ecosystem dynamics (Dong et al., 2014). The NDVI quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs). It is calculated by taking the difference between near-infrared (NIR) and red light reflectance values and dividing it by their sum. High NDVI values indicate dense and healthy vegetation, while low values suggest sparse or stressed vegetation.

NDVI plays a crucial role in providing insights into wetland vegetation dynamics and health. Changes in NDVI values indicate variations in wetland vegetation cover, biomass, and overall productivity (Q. Liu et al., 2020). Monitoring changes in NDVI over time helps identify wetland degradation, such as vegetation loss (Chen et al., 2022). By comparing NDVI values between different time periods, researchers can quantify changes in wetland vegetation and assess the impact of environmental factors, land use changes, or disturbances on wetland health. NDVI analysis enables the identification of areas experiencing vegetation decline or stress, aiding in the detection of degraded wetland areas. It also supports the development of conservation strategies by providing information on the effectiveness of wetland management practices (Dong et al., 2014)

2.5.2 Normalized Difference Water Index (NDWI)

NDWI, or Normalized Difference Water Index, is a remote sensing index used to assess water content and monitor water-related features within an area. It is calculated by taking the difference between near-infrared (NIR) and shortwave infrared (SWIR) reflectance values and dividing it by their sum (Guo et al., 2017b). NDWI values are particularly sensitive to changes in water content and can provide valuable information about wetland dynamics.

NDWI is utilized in wetland assessment to identify and monitor water bodies, wetland inundation levels, and hydrological changes. High NDWI values indicate the presence of water, while low values correspond to non-water features (Prajesh et al., 2019). By analyzing changes in NDWI over time, researchers can detect alterations in wetland water availability, extent, and hydrological patterns.

The use of NDWI in wetland assessment has shown promising results, allowing for the identification of wetland degradation processes such as water loss, drainage, or changes in wetland hydrology. Comparing NDWI values across different time periods provides insights into wetland water dynamics and can support conservation efforts by identifying areas experiencing water stress or decreased wetland inundation.

2.6 Environmental variables for wetland degradation

2.6.1 Climatic variables

The regional variation of climatic variables such as rainfall has a significant impact on wetland degradation, as they directly influence the hydrological regime, vegetation dynamics, and overall ecological processes within wetland ecosystems (D. Liu et al., 2017). Changes in rainfall patterns, temperature regimes, and hydrological conditions can lead to shifts in wetland water availability, vegetation stress, and alterations in ecosystem functioning. Understanding the regional changes of these climatic variables is crucial for assessing wetland degradation and predicting its future trajectories.

- **Rainfall**

Rainfall can be considered as one of the most critical drivers' wetland dynamics, changes in rainfall patterns, including alterations in intensity, duration, and frequency of precipitation events, can directly impact wetland ecosystems (D. Liu et al., 2017). Insufficient rainfall can result in water scarcity and drying of wetland habitats, leading to the loss of wetland vegetation and associated wildlife. Rainfall in Tanzania varies greatly throughout the FtF-ZoI region, ranging from semiarid terrain in Dodoma to humid climates in the Southern Highlands of Mbeya and Iringa. High annual rainfall (> 1200 mm) occurred in the Songwe and Njombe, commonly referred as Tanzania's Southern Highlands.

2.7 Topographic variables

These are the physical characteristics of the land surface within wetland areas. Wetlands can exhibit diverse topographic features that contribute to their unique hydrological and ecological characteristics(Xu & Chen, 2019). They provide valuable information about the physical characteristics of the wetland area, which have implications for hydrological processes.

i. Elevation

This is the vertical distance of a location above or below a reference point, such as sea level. Water inflow and outflow, along with water retention, are key aspects of wetland hydrology determined by elevation gradients. Higher elevations serve as water inflow areas where precipitation or runoff enters the wetland, while lower elevations act as water outflow areas where excess water drains out. This inflow-outflow dynamic contributes to the overall hydrological functioning of wetlands. Additionally, elevation variations within a wetland landscape create natural basins or depressions that retain water, supporting water storage within the wetland. Water retention is vital for maintaining the wetland's hydrological balance and providing suitable habitat conditions.

ii. Slope

It is a variable that defines the steepness or gradient of the land surface. Water flow and soil erosion are interconnected processes influenced by the slope of the land within wetlands. Slope determines the speed and direction of water movement within wetland ecosystems. Steeper slopes (e.g., 10% or more) result in faster water flow, potentially leading to increased erosion of soil particles. The erosion of soil can have detrimental effects on water quality, sedimentation processes, and overall wetland health.

iii. Aspect

Aspect refers to the compass direction that a slope faces. It describes the orientation of a land surface with respect to the cardinal directions (north, south, east, west). Aspect can influence evaporation rates in wetland ecosystems. The orientation of a slope determines the amount and intensity of solar radiation received by the land surface. Slopes facing south or southwest tend to receive more direct sunlight and higher solar radiation levels compared to slopes facing north or northeast. This differential solar radiation exposure can lead to variations in evaporation rates across different aspects within a wetland.

2.8 Spatial Analysis

Spatial analysis, or spatial data analysis, is a well-defined subset of the methods of analysis available to a project. One might define spatial analysis as a set of methods useful when the data are spatial, in other words when the data are referenced to a 2-dimensional frame(Goodchild & Longley, 1994). Additionally, spatial analysis allows for the integration of multiple data layers through overlay analysis, enabling the identification of areas where multiple factors coincide, exacerbating wetland degradation.

2.8.1 Multi-criteria analysis (MCA)

Multi-Criteria Decision Analysis (MCDA), also known as Multi-Criteria Decision-Making (MCDM), is the process of making decisions when multiple criteria (or objectives) must be considered simultaneously in order to rank or choose between alternatives in daily life, such as business, agricultural, health, environmental, and social problems in general. Most decisions made by individuals, groups, businesses, and governments that involve ranking or selecting between alternatives (including people) are amenable to MCDA.

2.8.2 Methods under Multi-Criteria Decision Analysis

There are several methods used in multi-criteria decision analysis to determine the suitability of an area over a specific condition. Analytical Hierarchy Process is one of these methods. Weighted Multi-criteria analysis (MCA) is a well-established approach for integrating and analyzing multiple criteria in decision-making processes (Estoque, 2011). MCA allows for the consideration of various factors that contribute to wetland condition and degradation. These factors can include ecological, hydrological, and socio-economic indicators. MCA involves several steps, starting with the identification of relevant criteria based on scientific knowledge, stakeholder input, and policy objectives(Song et al., 2022).

2.9 Analytical Hierarchy Process

AHP (Saaty 1977, 1990) is a multi-criteria decision-making method based on pairwise comparisons for elements in a hierarchy. It decomposes problems in a hierarchical structure and explicitly incorporates decision makers' expertise/experience in AHP evaluation. In AHP, the overall objective is located at the top of the hierarchy, and the criteria, sub criteria, and alternatives are placed at each descending level of the hierarchy. The user sets up a comparison matrix at each level to apply the principle of comparative judgment by comparing pairs of criteria, or pairs of alternatives at the lowest level. A scale of values ranging from 1 (indifference) to 9 (extreme preference) (Table 3) are used for the pairwise comparison of parameters. Once the matrix of pairwise comparisons has been developed, one can estimate the relative priority for each of the alternatives in terms of the specific criterion. Preferences derived from a criteria or subcriteria matrix are used to calculate a composite weight for each alternative. The typical approach to determining the weights from an AHP matrix is to take the Eigen vector corresponding to the matrix's largest Eigen value, normalize the sum of the components to one, and then calculate the weights from that matrix. The procedure entails constructing a pairwise matrix that would specify how many comparisons should be made based on how many factors are involved. The normalized scores obtained from the pairwise matrix are used to calculate the Eigen vectors for each factor Then calculation of consistency ratio (CR) is the third step that it is performed to identify inconsistencies and to develop the best weights in the complete pairwise comparison matrix and it involves using the following formula (Bunruamkaew, 2001).

$$CR = \frac{\mathrm{CI}}{RI} \text{...} (2.1)$$

Where CR = Consistency ratio, CI = Consistency index and RI = Random inconsistency index.

According to (Saaty, 2008) in a GIS multi-criteria analysis, the consistency index (CI) is computed using the formula:

$$CI = \frac{\lambda \max - n}{n-1} \text{...} (2.2)$$

Where n = the number of items being compared in the matrix, λmax = average value of the consistency ratio.

Table 2.1 Importance Scale

Intensity of importance	Definition	Explanation
1	Parameters are of equal importance	Two parameters contribute equally to the objective
3	Parameter I is of more importance compared to parameter J	Experience and judgement strongly favor I over J
5	Essential or strong importance of I compared to J	Experience and judgement strongly favour I over J
7	Very strong or demonstrated importance	Criteria I is very strongly favoured over J and its dominance is demonstrated in practice
9	Absolute importance	The evidence favouring, I over J to the highest possible order of affirmation
2,4,6,8	Intermediate values between two adjacent judgement	Judgement is not precise enough to assign values of 1, 3, 5, 7 and 9 (compromise is needed)

CHAPTER THREE

METHODOLOGY

3.1 Overview

This chapter describes the overall workflow used in this study, it includes the data collection, data preprocessing and data analysis methods that were used in obtaining the results. The methodology hinges on a Multi-criterion analysis (MCA) with weighted overlay to assess wetland degradation by integrating multiple variables using Analytical Hierarchy Process. The methodology allows for the consideration of multiple criteria, their interdependencies, and uncertainties in wetland degradation assessment.

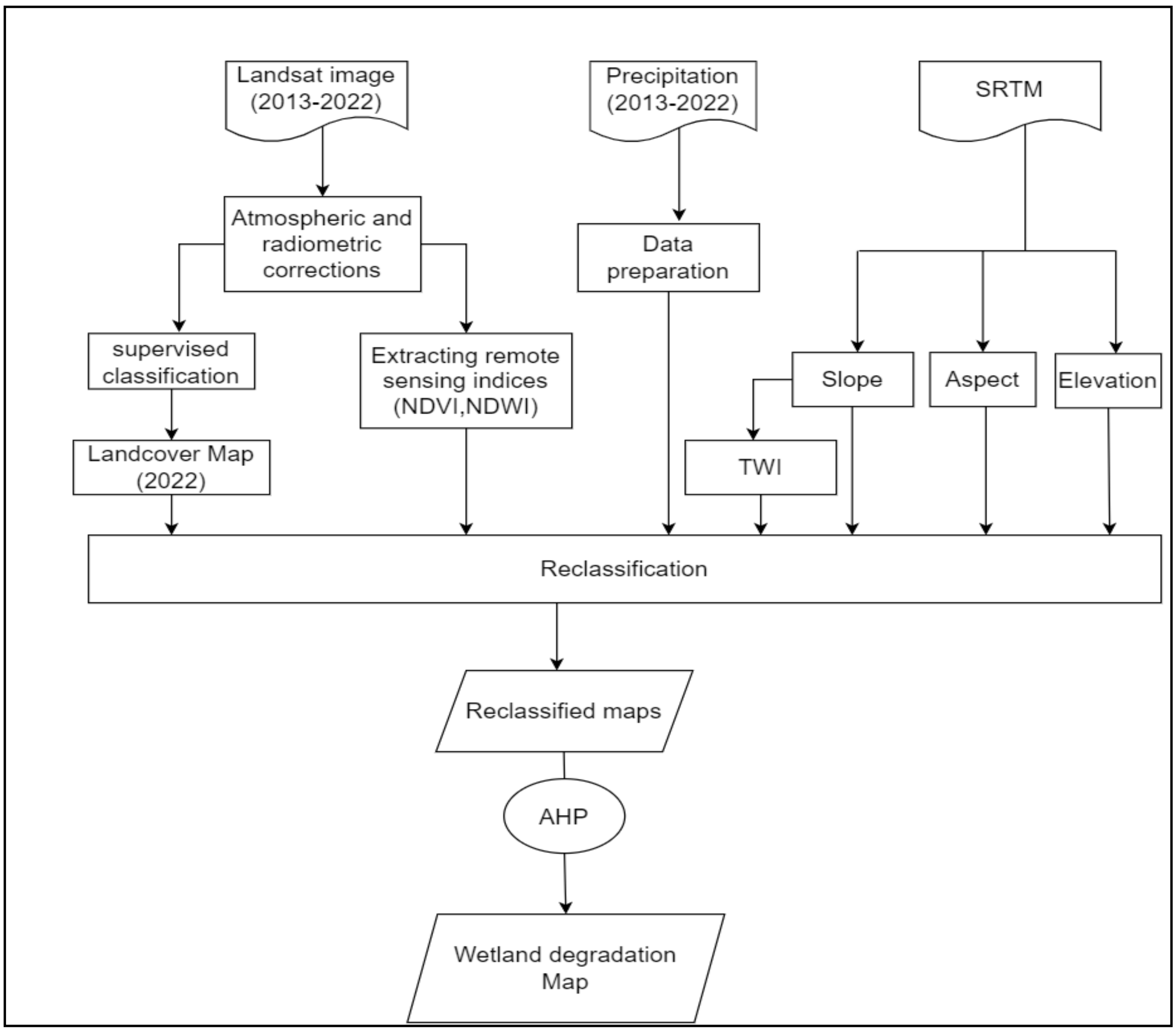

Figure 3. 1 workflow

3.2 Description of the study area

The Usangu Plains are found in the south-west part of Tanzania. The region stretches between 33º 00’E and 35º 00’E longitudes, and 8º 00’S and 9º 30’S latitudes, covering a total area of about 4,480 km2. With an average elevation of 1,100 meters above sea level, the Usangu Plains are surrounded by the Poroto, Kipengere and Chunya mountain ranges, which rise up to 3,000 meters above sea level. The Usangu Wetland is comprised of a complex of interconnected wetlands, including rivers, swamps, and lakes. The Usangu Wetland is considered one of the largest and most important wetlands in Tanzania, and is recognized as an important site for biodiversity conservation. The basin has two distinct parts, a mountainous and heavily forested region with high rainfall in the south and a flat plain in the north. The flat plain is composed of large alluvial fan areas, which support the majority of the settlements in the region and also contain both irrigated and dryland farming.

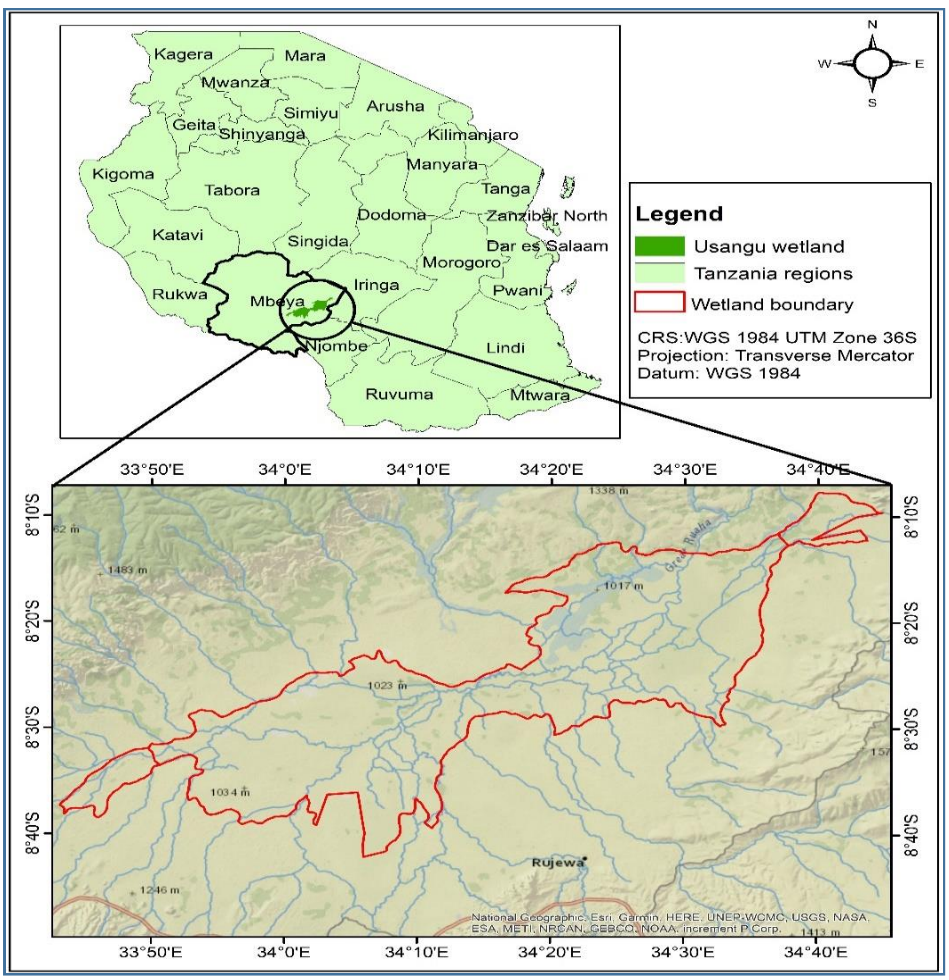

Figure 3. 2 location map of the study area

3.3 Data collection and description

The data utilized in this research were obtained from diverse sources and were available in various formats. A summary of the data sources and formats can be found in Table 3.1, which provides an overview of the data used in the study.

Table 3. 1 Data used and their sources

NAME	SOURCE	FORMAT	RESOLUTION
Landsat 8 images	USGS	Tiff.	30m
Precipitation	Chirps	Tiff.	0.05°
Elevation (DEM)	USGS	Tiff.	30m
Administration boundary	GADM	Shp.	

3.3.1 Climatic data.

i. Rainfall

The quantity, frequency, and distribution of rainfall play a crucial role in wetland degradation. Rainfall is a primary source of water for wetland ecosystems, and its availability directly affects the overall health and functioning of these habitats. In regions experiencing decreased or irregular rainfall patterns, wetlands are particularly vulnerable to degradation. Figure 3.3 shows the rainfall distribution in the Usangu wetland.

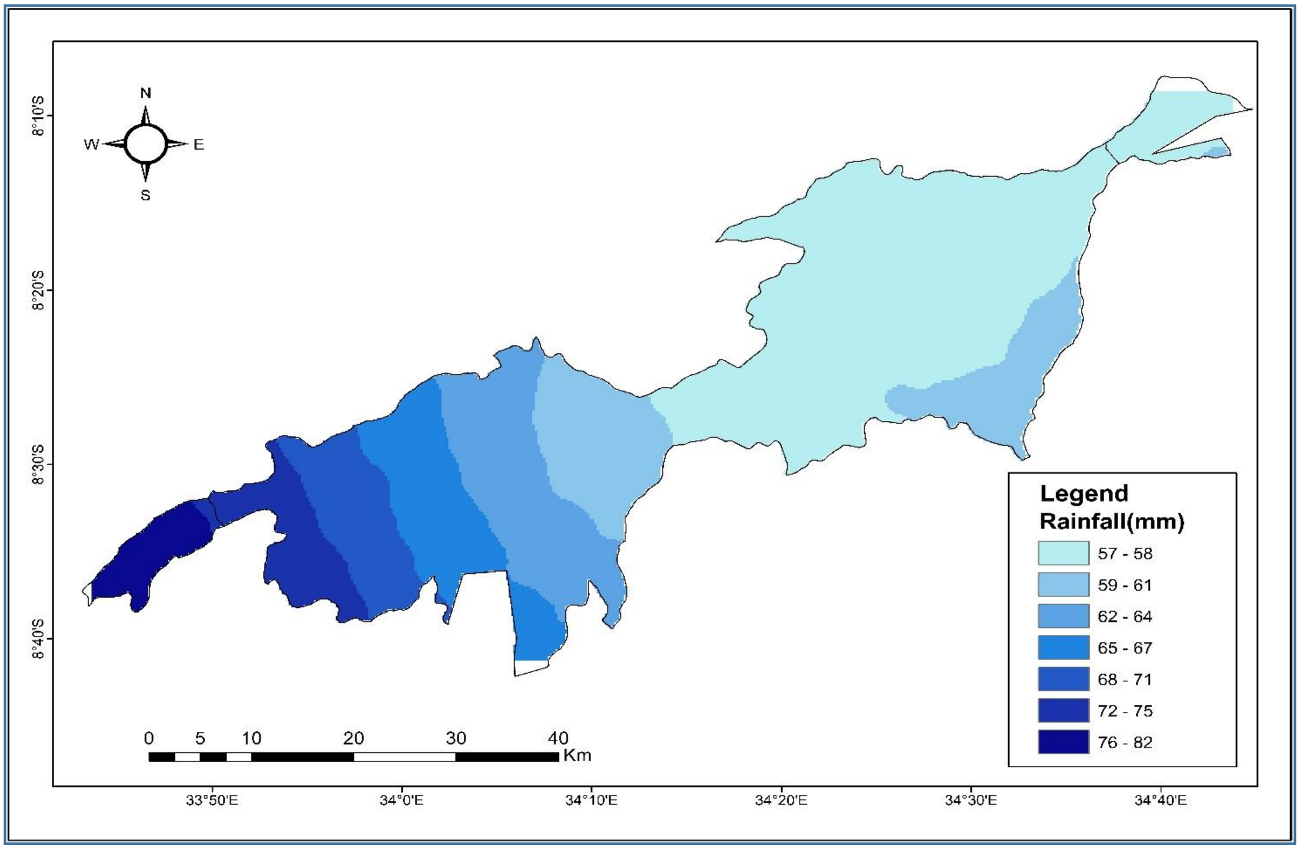

Figure 3. 3 Rainfall distribution map

3.3.2 Landsat data

Landsat 8 images acquired from USGS (2013-2022) were used for image classification due to their high spatial resolution and spectral bands that provide valuable information for land cover analysis. Landsat 8 Operational Land Imager (OLI) sensor captures data in several spectral bands, including visible, near-infrared, and shortwave infrared, allowing for the differentiation of various land cover types.

The images were also used to compute NDVI and NDWI composites for each of the study years. Image composites were preferred to singular images for better representation of annual phenomena, and also for cloud masking.

3.3.3 Raster surface analysis

i. **Digital Elevation Model (DEM)**

The DEM from Shuttle Radar Topographic mission (SRTM) was downloaded from USGS having a spatial resolution of 1 arc-second (30m). It was used to acquire the elevation of different areas of the wetland which can help in determining areas of the wetland that are more likely to undergo degradation due to water runoffs caused by high elevations. Western and eastern parts of the Usangu wetland are characterized by different elevation ranging from lowlands to highlands.

ii. Slope and aspect

The slope algorithm of the horn method was used to calculate the slope values from the digital elevation model because it yields a higher density of flow vectors than any other method and is therefore more sensitive to noise than local methods. This slope information is valuable for wetland assessment, as it helps to identify areas with varying degrees of slope, which can influence water flow, soil erosion, and wetland dynamics.

iii. Topographic Wetness Index (TWI)

Topographic Wetness Index (TWI) was developed using the digital elevation model in ArcMap software. The topographic wetness index (TWI, ln(a/tan)), which combines the local upslope contributing area and slope, is frequently used to quantify topographic control on hydrological processes. The following are the procedures of acquiring the Topographic Wetness Index (TWI**)**

a) Flow direction is calculated from the DEM
b) Flow accumulation is generated from the Flow direction
c) Slope is generated from the DEM
d) New slope (Slope2) is generated from the DEM
e) $Slope2 = (slope(DEM) * 1.570796)/90$
f) Tan of the slope is generated utilizing the results of the previous step
g) Tan_slp $= con\ (slope > 0, \tan(slope), 0.001)$
h) A scaled flow accumulation is obtained by multiplying with the cell-size
i) Fa scaled= $(fa + 1) * cellsize$, where fa= flow accumulation
j) Then finally the Topographic Wetness Index was generated from the scaled flow accumulation and the tan_slp

$$TWI = ln(Fa\_scaled/Tan\_slp)\ , where\ slp = slope \ldots\ldots\ldots\ldots \quad (3.1)$$

3.3.4 Landsat data

Landsat 8 images acquired from USGS (2013-2022) were used for image classification due to their temporal resolution that provide valuable information for land cover analysis. The United States Geological Survey (USGS) offers a series of Landsat satellites available on the GEE platform from Landsat 4 to Landsat 9. The data is divided into 2 tiers according to quality, with Tier 1 containing the highest quality data currently available and Tier 2 holding the rest. Then the Tier 1 and images with less than 30% cloud cover to define the collection were selected. The images were also used to generate NDVI and NDWI composites for each of the study years.

3.4 Extraction of Remote sensing indices

3.4.1 Calculating the indices

The corrected images were then used to compute various indices for each year from 2013 to 2022, including the Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI). The “addVariables” function played a crucial role in this step, as it added the necessary bands for each index calculation.

i. NDWI Calculation:

The Normalized Difference Water Index (NDWI) was used as an indicator of water presence in the wetland, with higher NDWI values indicating areas with a greater presence of water. The Normalized Difference Water Index (NDWI) was obtained from Landsat 8 satellite images captured from 2013-2022. The NDWI values were calculated for each image using the formula:

$$\mathrm{NDWI} = \frac{(\mathrm{NIR} - \mathrm{SWIR})}{(\mathrm{NIR} + \mathrm{SWIR})} \quad (3.2)$$

where NIR represents the near-infrared reflectance values and SWIR represents the shortwave infrared reflectance values (Kshetri, 2018).

Using Google Earth Engine, the Normalized Difference Water Index (NDWI) was calculated using the formula "(image.normalizedDifference(['B5', 'B6'])). rename('NDWI')". The NDWI values were then extracted and exported as a raster layer for further analysis.

ii. NDVI Calculation:

The Normalized Difference Vegetation Index (NDVI) was used as an indicator of vegetation health and density in the wetland, with higher NDVI values representing areas with denser and healthier vegetation. The Normalized Difference Vegetation Index (NDVI) was obtained from Landsat 8 satellite images captured from 2013-2022. The NDVI values were calculated for each image using the formula (Allestro, 2015):

$$\mathrm{NDVI} = \frac{(\mathrm{NIR} - \mathrm{Red})}{(\mathrm{NIR} + \mathrm{Red})} \quad (3.3)$$

where NIR represents the near-infrared reflectance values and Red represents the red reflectance values. The Normalized Difference Vegetation Index (NDVI) using Google Earth Engine, was calculated using the formula "(image.normalizedDifference(['B5', 'B4'])).rename('NDVI')". The NDVI values were then extracted and exported as a raster layer for further analysis.

3.5 Supervised Image Classification

i. Training Data Collection and Preparation

The spectral bands from the 2022 Landsat 8 image, including Blue, Green, Red, and Near-Infrared, were selected as input features for the classification and the training data was collected by selecting representative samples from the study area. These samples were carefully labeled with the corresponding land cover classes which are (bareland, Grassland, dense vegetation, and water bodies).

ii. Training the Random Forest Classifier

Using the training data collected, the samples were randomly split into two sets: a training set comprising 70% of the samples and a validation set comprising the remaining 30% of the samples. The training set, consisting of a majority of the samples, was used to train the Random Forest classifier in Google Earth Engine (GEE). This involved utilizing the "ee.Classifier" and "ee.Classifier.RandomForest" classes available in GEE. The classifier learned the spectral patterns from these training samples and created decision trees based on the provided features. The validation set, representing a smaller portion of the samples, was then used to assess the accuracy of the classification results and evaluate the model's performance. This 70-30 split ensured a sufficient amount of training data while allowing for an independent validation of the classifier's performance.

iii. Land cover Classification

Once the Random Forest classifier was trained using the training data, it was applied to the entire image to classify each pixel into specific land cover classes. The resulting classified map provided information about the distribution and spatial extent of different land cover types within the study area. This classification process involved assigning a class label to each pixel based on its spectral characteristics and the learned patterns from the training samples.

3.6 Reclassification

In this research the factors that were used for this assessment were reclassified thus including the slope, aspect, elevation, NDVI, NDWI, TWI and the landcover map which are all thematic layers in multi-criteria analysis. Each raster dataset was loaded in ArcGIS and the reclassify tool from Spatial Analyst was used to specify the parameters and allocate new values from the old values based on the specific criteria. The outputs were reclassified into five classes.

3.7 Analytical Hierarchy Process

In AHP, firstly pairwise comparison of criteria was performed and the results were put in a pairwise comparison matrix

Table 3. 2 Pairwise comparison of criteria

	NDVI	Landcover	Precipitation	NDWI	Elevation	TWI	Slope	Aspect
NDVI.	1	2	5	7	2	5	2	2
Landcover	0.5	1	3	4	3	5	6	4
Precipitation	0.2	0.333	1	5	3	7	3	2
NDWI	0.143	0.25	0.2	1	2	5	3	4
Elevation	0.5	0.333	0.333	0.5	1	7	9	3
TWI	0.2	0.2	0.143	0.2	0.143	1	5	2
Slope	0.5	0.167	0.333	0.333	0.2	0.111	1	5
Aspect	0.5	0.25	0.5	0.25	0.333	0.5	0.2	1
total	3.543	4.533	10.509	18.283	11.676	30.611	29.2	23

The weight for each criterion was then calculated by dividing the values of each criterion by the total of all column values and the obtained rows values were then arranged to calculate the weight of each criterion, where the total weight should be equal to one. A standardized matrix with all obtained criteria weights is shown in the table below

Table 3.3 Standardized Matrix

	NDVI	Landcover	Precipitation	NDWI	Elevation	TWI	Slope	Aspect	Weight
NDVI.	0.28	0.44	0.48	0.38	0.17	0.16	0.07	0.09	0.20
Landcover	0.14	0.22	0.29	0.22	0.26	0.16	0.21	0.17	0.20
Precipitation	0.06	0.07	0.10	0.27	0.26	0.23	0.10	0.09	0.16
NDWI	0.04	0.06	0.02	0.05	0.17	0.16	0.10	0.17	0.12
Elevation	0.14	0.07	0.03	0.03	0.09	0.23	0.17	0.13	0.13
TWI	0.06	0.04	0.01	0.01	0.01	0.03	0.31	0.09	0.10
Slope	0.14	0.04	0.03	0.02	0.02	0.00	0.03	0.22	0.06
Aspect	0.14	0.06	0.05	0.01	0.03	0.02	0.01	0.04	0.03
total	0.28	0.44	0.48	0.38	0.17	0.16	0.07	0.09	0.20

After the pairwise comparison matrix was created and the sum of columns in the pairwise matrix was calculated, a normalized pairwise comparison matrix was obtained. This was done by dividing each element of the pairwise comparison matrix by its corresponding column sum. Then the row averages were calculated by adding up the values in each row and dividing by the total number of criteria. The resulting row averages represented the normalized weights for each criterion which indicate the relative importance of each criterion in relation to the others.

Table 3.4 Normalized Matrix

	NDVI	Landcover	Precipitation	NDWI	Elevation	TWI	Slope	Aspect	weight	W/s	W/s/w
NDVI.	0.20	0.40	0.82	0.83	0.27	0.49	0.12	0.05	0.20	3.38	6.90
Landcover	0.10	0.20	0.49	0.47	0.40	0.49	0.35	0.11	0.20	2.82	7.58
Precipitation	0.04	0.07	0.16	0.59	0.40	0.69	0.17	0.05	0.16	2.35	14.32
NDWI	0.03	0.05	0.03	0.12	0.27	0.49	0.17	0.11	0.12	1.39	11.58
Elevation	0.10	0.07	0.05	0.06	0.13	0.69	0.29	0.08	0.13	1.61	7.51
TWI	0.04	0.04	0.02	0.02	0.02	0.10	0.52	0.05	0.10	0.92	9.38
Slope	0.10	0.03	0.05	0.04	0.03	0.01	0.06	0.13	0.06	0.52	8.86
Aspect	0.10	0.05	0.08	0.03	0.04	0.05	0.01	0.03	0.03	0.42	5.02

The CI was then calculated, by first computing the weighted sum for each column by multiplying each element's value by its corresponding weight and then summing up the results. The principal eigenvalue (λ_max) wass determined by averaging these weighted sums

$$\text{CI} = \frac{8.8901-8}{8-1}$$

$$\text{CI} = 0.127157$$

Then the Consistency Ratio (CR) is computed by dividing the CI by the Random Index (RI), which is a reference value based on the number of elements being compared.

$$\text{Then, } CR = \frac{CI}{RI}$$

$$\text{CR}= \frac{0.127157}{1.41}$$

$$\text{CR} = 0.09018$$

CHAPTER FOUR

RESULTS, ANALYSIS AND DISCUSSION

4.0 Overview

The chapter provides a detailed review of the research findings and results through the use of maps and graphs for analysis.

4.1 Normalized difference vegetation index

The analysis of NDVI reveals the state of vegetation cover in the wetland. The NDVI values from -0.19-0.15 revealed areas in the wetland that were covered by water such as the seasonal rivers in the wetland. The range 0.16-0.25 revealed areas in the wetland that are not covered by vegetation (bareland), a larger area (western part of the wetland) is seen to have very little vegetation as compared to the eastern part. The eastern part of the wetland is largely covered by sparse and dense vegetation as indicated by the values from 0.26- 0.7 with the higher values showing healthier vegetation signifying that the eastern part of the wetland is healthier than the western part as seen from Figure 4.1 below.

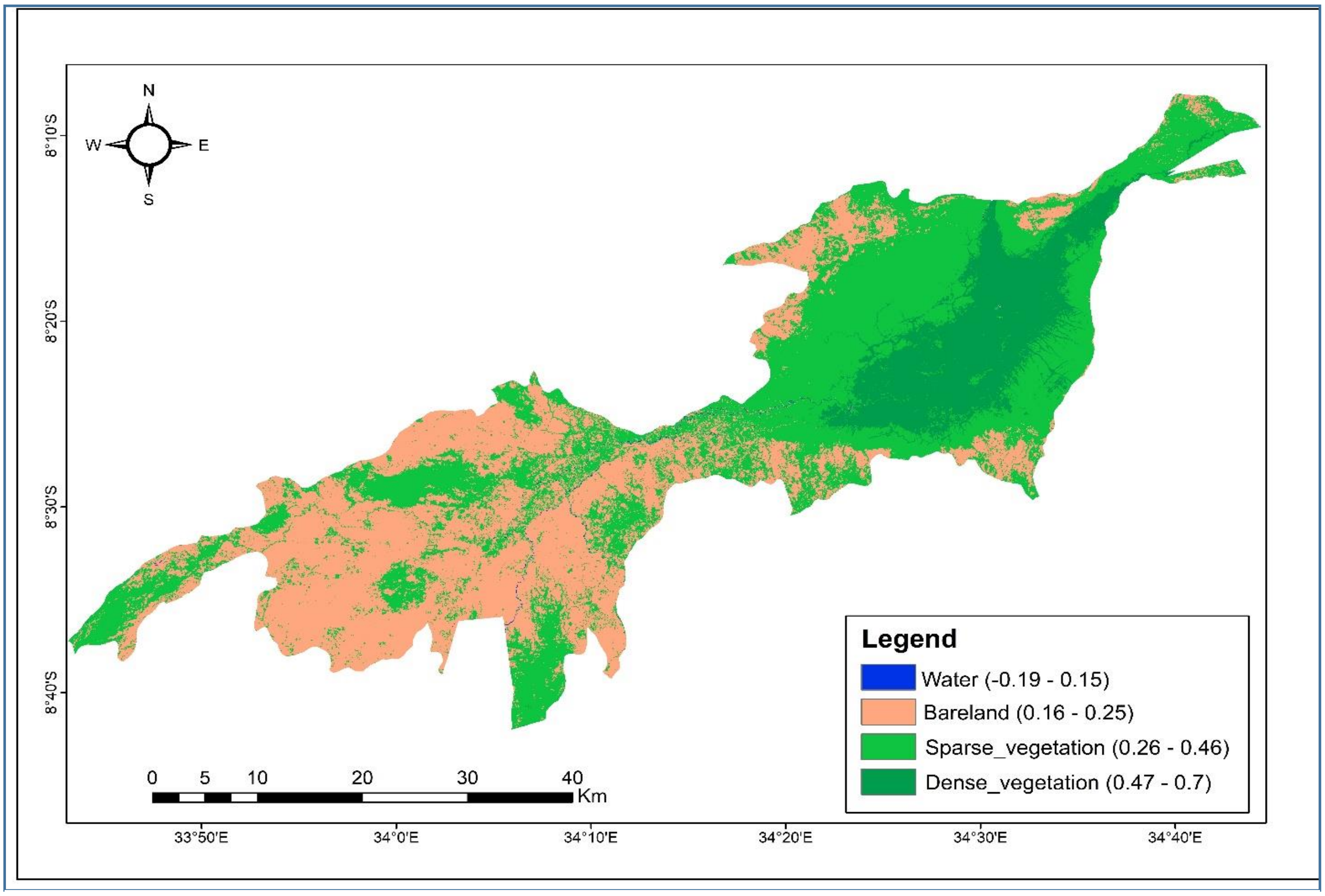

Figure 4.1 NDVI Map of Usangu Wetland

4.2 Normalized Difference Water Index (NDWI)

NDWI results obtained from the analysis showed values from (-0.3- -0.15), with lower values (below zero) showing areas with low water content which is dominant in the western part of the wetland. The low water content coupled with significant lack of vegetation shows that degradation is persistent in western part of the wetland. The NDWI values above zero shows areas of the wetland that have moderate to high water content which can be observed in the eastern part of the wetland this indicates good health (no degradation) due to the availability of water and vegetation that thrive in waterlogged conditions. From this results it can be observed that the eastern wetland has little to no degradation as can be seen from the Figure 4.2 which illustrates distinct variations between the western and eastern sections of the wetland, with notably lower moisture content observed in the western part.

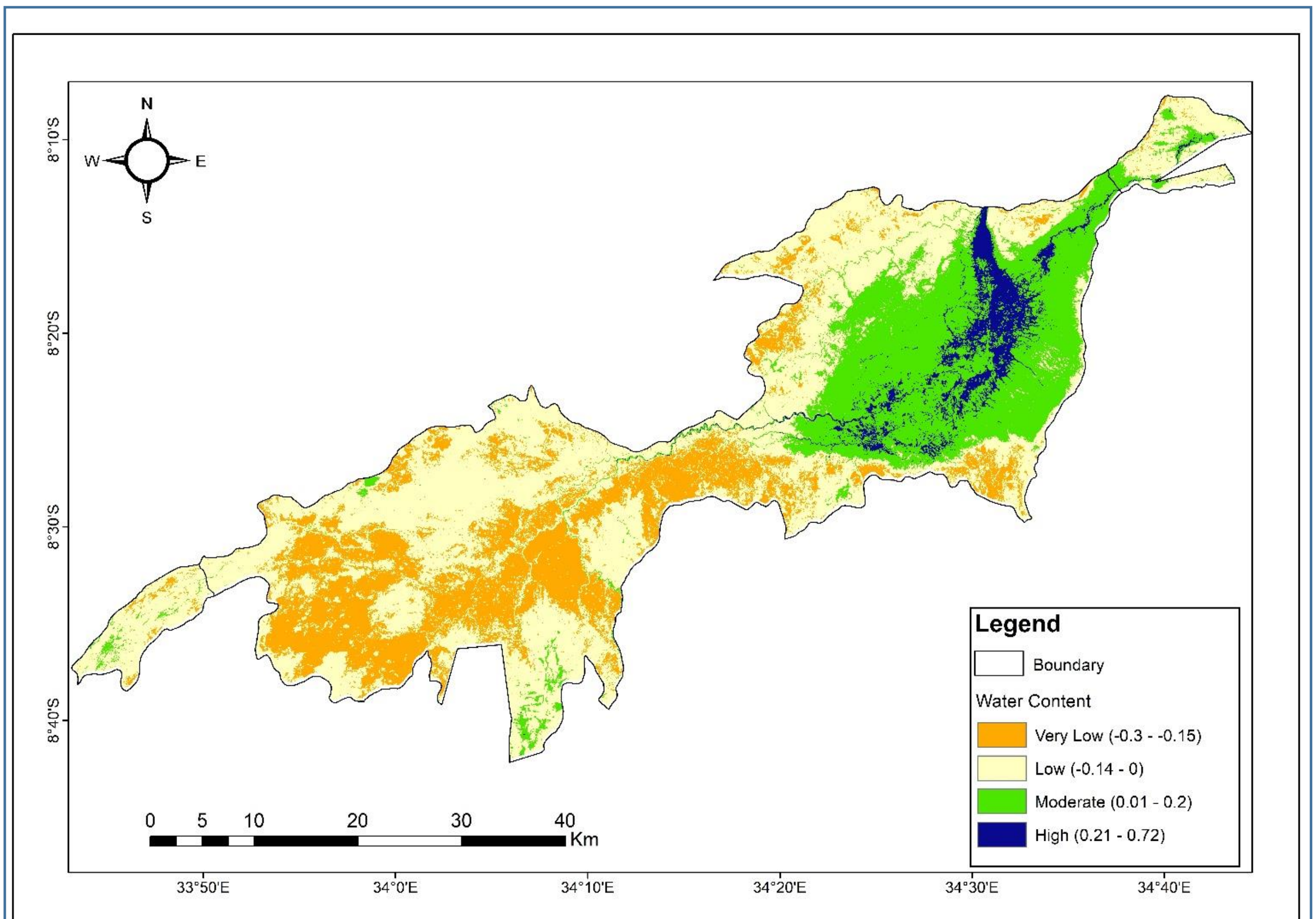

Figure 4.1 NDWI Map of Usangu Wetland

4.2 Topographic wetness index (TWI)

The obtained Topographic Wetness Index (TWI) results reveal significant variations in wetland topography, directly impacting its degradation processes. The analysis yielded a range of TWI values, with the highest value recorded as 11.9854 and the lowest as 2.8412.

Higher TWI values point towards relatively flat terrains with efficient water accumulation potential, highlighting areas conducive to maintaining healthy wetland conditions. These regions play a crucial role in supporting water retention and encouraging vibrant wetland ecosystems. In contrast, lower TWI values correspond to uneven landscapes, suggesting compromised water retention capacity and altered water flow patterns. Such areas may face challenges in preserving consistent water availability, contributing to wetland degradation through disrupted hydrological processes. Figure 4.3 visually underscores the contrast between high and low TWI value zones, reaffirming their distinct roles in shaping wetland dynamics and influencing degradation trends.

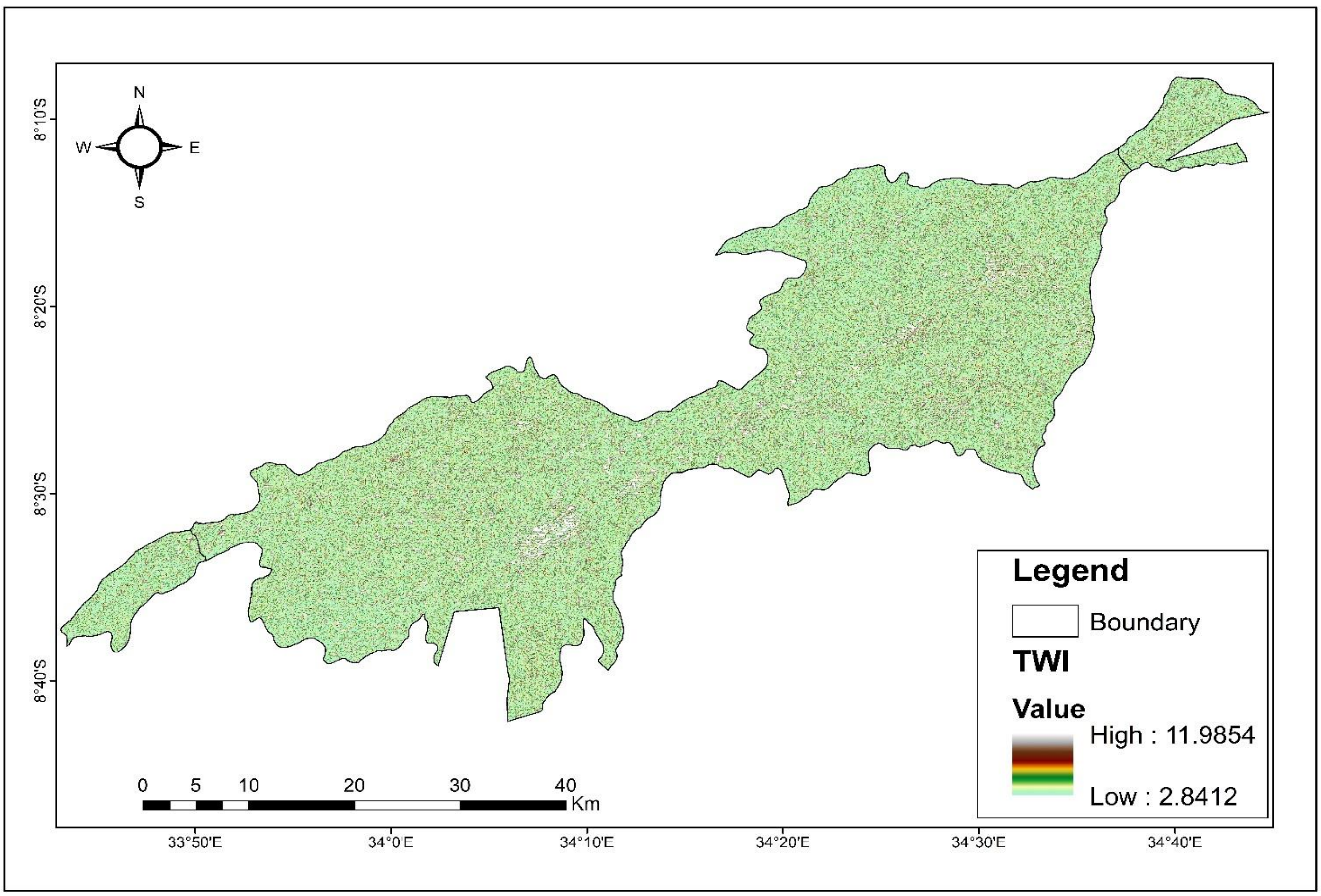

Figure 4.2 TWI map of Usangu Wetland

4.3 Elevation

Analyzing the digital elevation model (DEM) data reveals distinct elevation ranges within the study area. The highest recorded elevation is 1085 meters, while the lowest is 1003 meters. These findings highlight a notable difference between the western and eastern regions. The eastern area demonstrates slightly higher elevations, which can impact water movement and distribution across the wetland. In contrast, the western region predominantly consists of lower-lying areas. These elevation disparities, as visualized in Figure 4.4, underscore the topographical diversity within the wetland and its implications for wetland degradation processes.

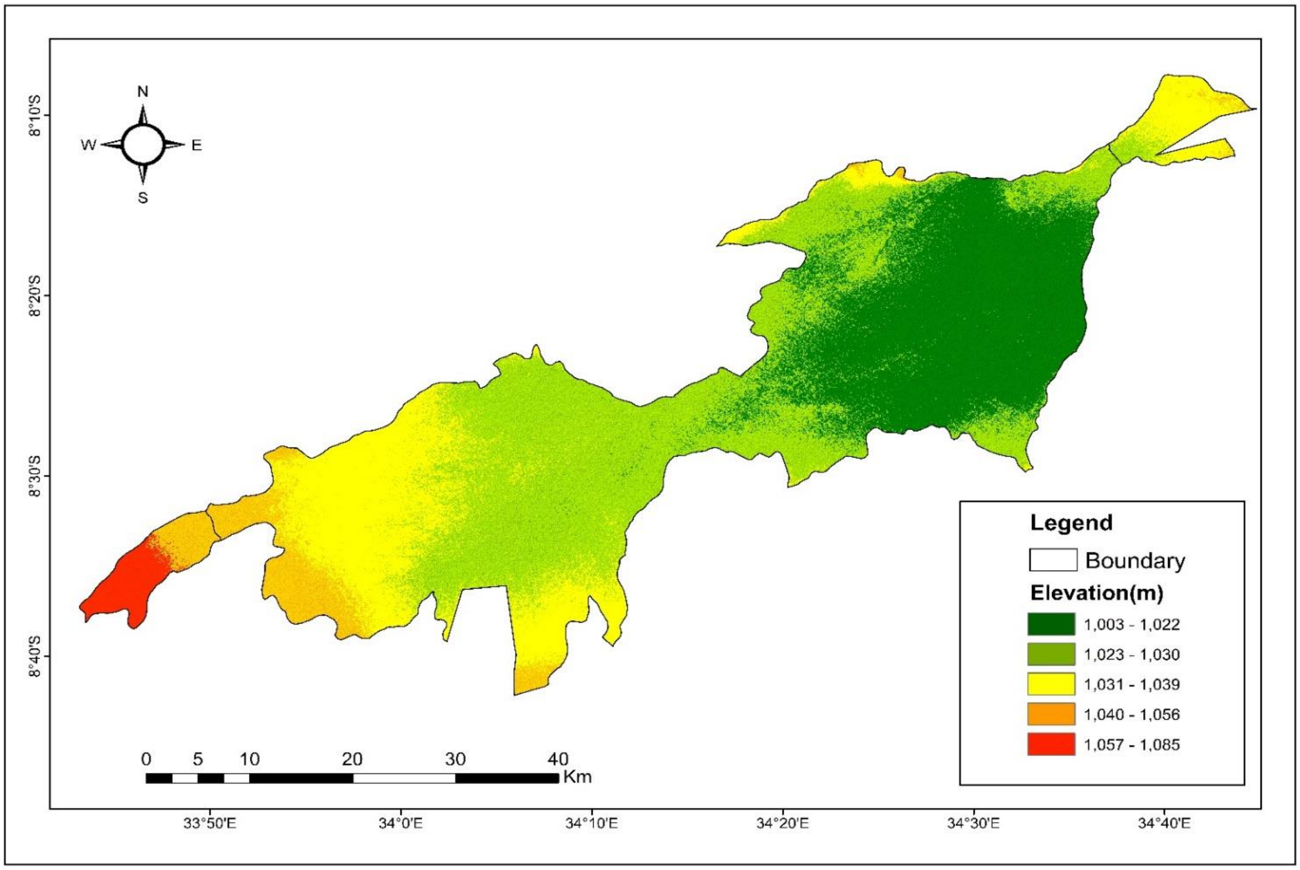

Figure 4.3 Elevation map of Usangu wetland

4.4 slope and aspect

The analysis of the DEM into the studied wetland areas indicates a slope range spanning from 0 to 11 degrees. This seemingly gentle slope range still holds notable implications for water dynamics and soil moisture content, even in wetland ecosystems. Even subtle slopes within this range can significantly influence wetland health. Areas with slopes closer to 0 degrees' experience slower water runoff, allowing increased time for water infiltration and soil moisture replenishment. This nurturing effect fosters robust wetland vegetation and habitats, sustaining a diverse array of plant and animal species.

Conversely, aspect, which is the orientation of the slope, significantly affects wetland hydrological characteristics. The positioning of the slope relative to cardinal directions impacts water availability, evaporation rates, and moisture retention. For instance, wetlands with south-facing slopes tend to encounter higher evaporation rates due to heightened solar radiation exposure. This scenario can lead to water stress and reduced wetland productivity. In contrast, wetlands with north-facing slopes receive more shade and cooler temperatures, promoting enhanced moisture retention. This creates a conducive environment for wetland vegetation and wildlife, thereby contributing to wetland preservation.

4.5 Landcover classification

The generated land cover maps consisted of four distinct landcover classes: Bareland, Grassland, dense vegetation, and water bodies. The quantity and quality of vegetation cover exert a significant influence on landscape development, its capacity for resilience, and its susceptibility to degradation (Symeonakis and Drake, 2004). Upon analyzing the study area, it became apparent that by 2022, the dominant land cover type was predominantly bareland (51.84%), trailed by grassland (22.99%), dense vegetation (15.53%), and water (9.65%). This output of land cover also exhibited changes relative to the 2016 landcover map, indicating shifts in the distribution of classes within the wetland. Comparing the two years, there was a noticeable increase in the coverage of certain classes while the coverage of others decreased as can be seen from the graph in Figure 4.5 Specifically, in the 2016 land cover map, the grassland class held the highest coverage at 62.81%, followed by bareland at 21.69%, dense vegetation at 7.44%, and water at 8.05%. This comparison underscores a notable decrease in vegetation cover in the more recent years, as demonstrated in Figure 4.6.

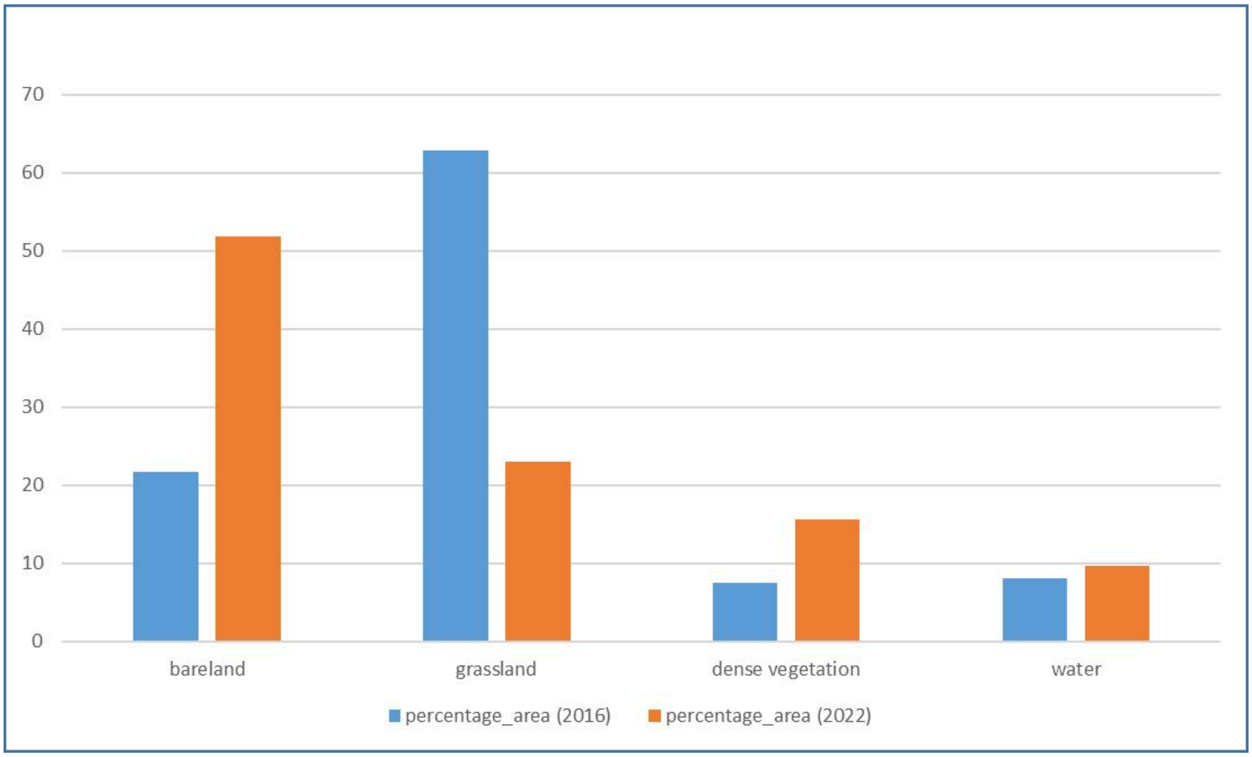

Figure 4.4 Percentage coverage of landcover classes (2016,2022)

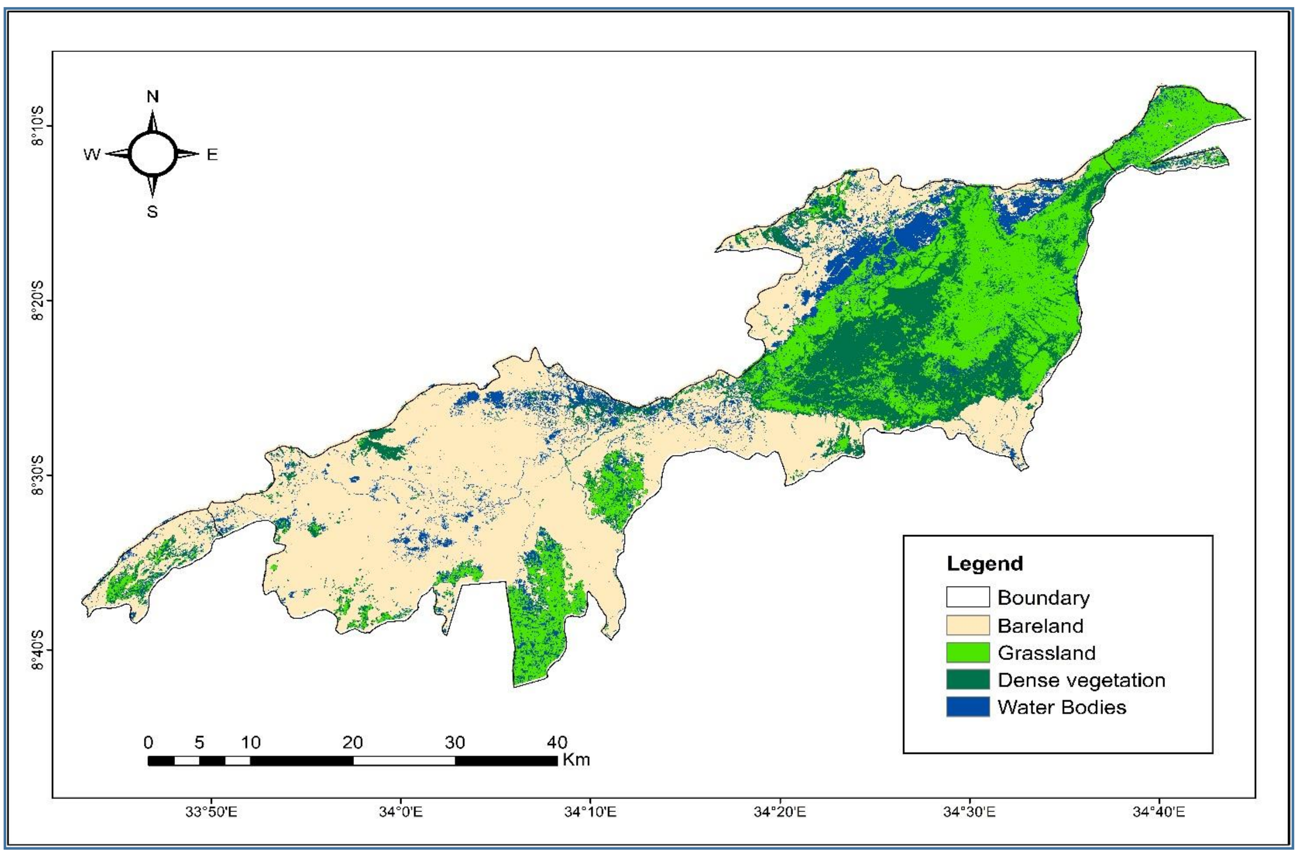

Figure 4.5 Landcover map of Usangu wetland (2022)

4.5 Wetland degradation map

The analysis revealed significant insights into the wetland's degradation status. The resulting wetland degradation map, shown in Figure 4.6, vividly indicates the severity of degradation across the study area. The map is categorized into five distinct levels, each representing a varying degree of wetland degradation. The findings demonstrate that the largest proportion of the wetland, approximately 38.08% of its total area, falls within the category of moderate health. This is followed by areas exhibiting high degradation at 29.11%, while 18.52% showed no degradation. Additionally, regions with low degradation cover 11.93% of the wetland, and the smallest portion, constituting 2.35%, demonstrated the highest degree of degradation. These findings collectively provide a comprehensive understanding of the distribution and severity of wetland degradation in the studied area.

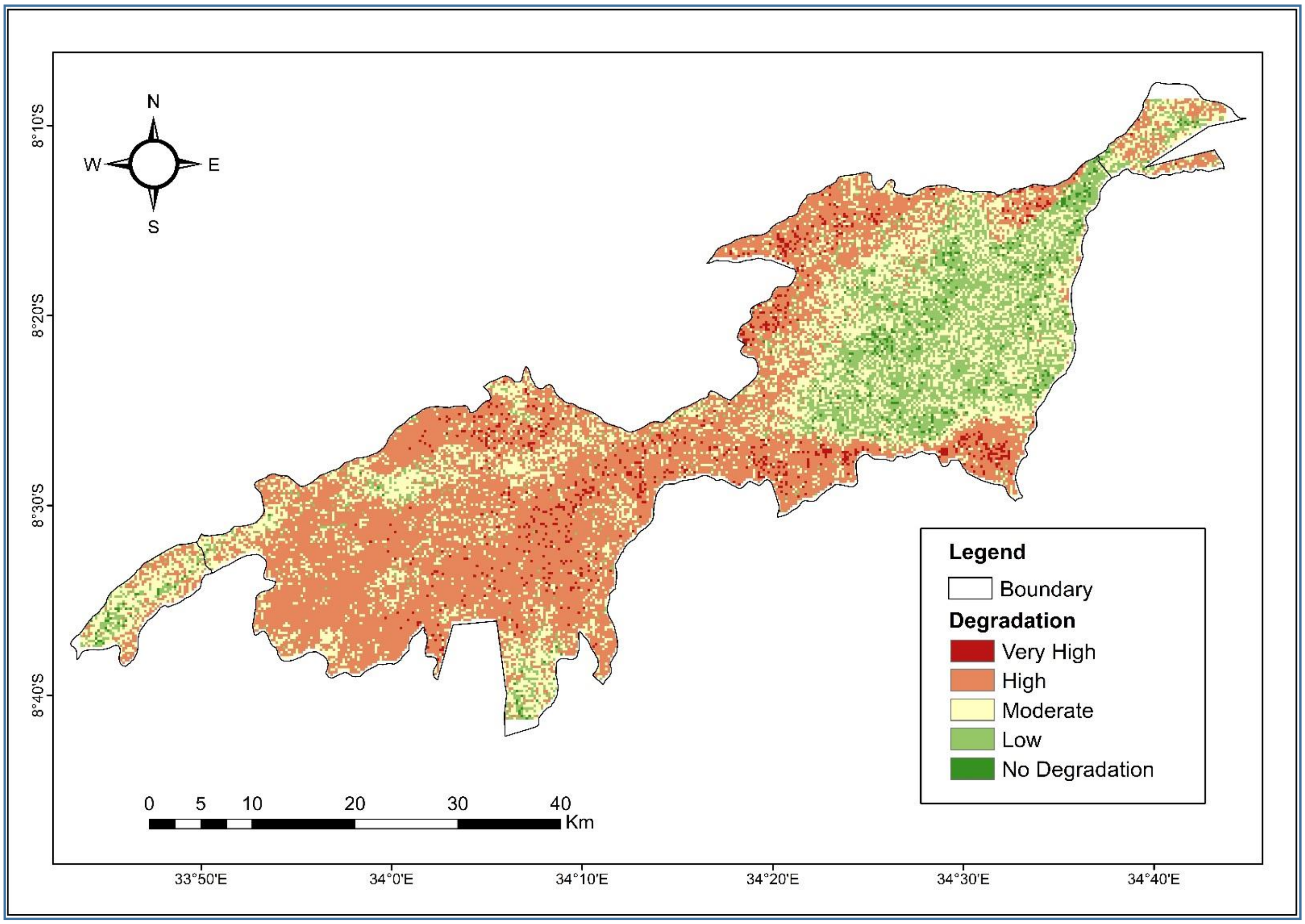

Figure 4.6 Usangu Wetland degradation Map

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The research on wetland degradation, focusing on the Usangu wetland, has provided valuable insights into the causes and extent of degradation in the area. The study highlighted the significant degradation experienced in the western part of the wetland compared to the eastern part, primarily due to conflicting water resource usage and competing demands.

The land cover map revealed a depletion of vegetation cover in the western wetland, with large areas of bareland and sparse vegetation, while the eastern wetland exhibited healthier vegetation, particularly around the swamp area. This finding emphasizes the need for urgent action to address the degradation and restore the wetland's ecological integrity.

The analysis of NDVI and NDWI in the study revealed significant findings regarding the degradation of the Usangu wetland. The results showed a marked difference in vegetation cover between the western and eastern parts of the wetland. The western region exhibited depleted vegetation cover, characterized by extensive bareland and sparse vegetation. In contrast, the eastern wetland displayed healthier vegetation, particularly around the swamp area. This disparity suggests that the degradation of the Usangu wetland is primarily manifested through the loss of vegetation in the western region, indicating the need for targeted restoration efforts to address the observed vegetation decline.

By considering all these factors together, a comprehensive assessment of the Usangu wetland degradation emerges. The competing water usage, depletion of vegetation cover, and the findings from NDVI and NDWI analysis collectively indicate a significant decline in wetland health, particularly in the western region. This assessment emphasizes the urgent need for sustainable water management, restoration efforts, stakeholder collaboration, and monitoring to address the degradation and restore the ecological integrity of the Usangu wetland.

5.2 Recommendations

The method used in this research is AHP which relies heavily on the judgments and preferences of the decision-makers involved. This subjectivity introduces the possibility of bias and variations in individual judgments, which can influence the overall results and decision outcomes. Further research can be done by using other methods that do not rely on this subjectivity.

Wetlands are dynamic systems therefore it is important to continuously monitor and evaluate the wetland's ecological indicators, such as water quality and vegetation cover. This will help assess the effectiveness of management interventions, track changes over time, and inform adaptive management strategies. Invest in research and data collection to gain a deeper understanding of wetland dynamics, identify the root causes of degradation, and inform evidence-based decision-making and policy development.

It is crucial to strengthen wetland conservation measures. This involves implementing comprehensive strategies to protect wetland areas, including the establishment of protected areas and the enforcement of regulations against detrimental activities such as land conversion and unsustainable resource extraction. Additionally, promoting sustainable land management practices and raising awareness among local communities about the importance of wetlands can contribute to their long-term preservation.

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