AN ASSESSMENT OF RIVER AND WETLAND MORPHOLOGY DYNAMICS USING GEOSPATIAL TECHNIQUES

By

Yamkela Mbambi

A thesis submitted in fulfilment of the requirements for the degree of Magister Scientiae in Environmental and Water Science

In

Faculty of Natural Science

University of the Western Cape, South Africa.

Supervisor: Professor Timothy Dube

ABSTRACT

Land surface modification has intensified in recent years, and it continues to be an ongoing process. This raises serious concerns about changes in land use and land cover (LULC) since some of these changes have led to catchment degradation. The degradation of catchments has been observed to have adverse effects on natural resources, such as water bodies, resulting in food insecurity, water scarcity, and the degradation of ecosystems and the environment. Therefore, to effectively sustain life and the environment, it is crucial to monitor LULC changes for sustainable development and planning that can help alleviate pressures on water resources. This study aims to assess the impacts of LULC changes on the morphology dynamics and area changes of water resources in the Heuningnes catchment in South Africa. The findings from this assessment can offer valuable insights for water resource conservation in this catchment. Remote sensing and GIS techniques were employed to map and detect LULCchanges, morphology dynamics, and area changes of water resources from 1990 to 2020. Image enhancements using band combinations and LULC classifications using maximum likelihood, along with post-classification methods, were used for LULC change detection. Spectral indexing (MNDWI) and on-screen manual digitization were used to extract wetlands and rivers from Landsat TM and OLI imagery for evaluating morphology dynamics. The study results revealed that agriculture and vegetation classes were the main contributors to the reduction of water body sizes in this catchment. Their spatial distributions extended mostly in the vicinity of regions with concentrated water bodies, particularly in the low-flat terrain of the catchment. Over the specified time intervals of 1990-2015, 2015-2017, 2017-2020, and 1990-2020, the wetland area experienced reductions of 4.06 km^2, 1.34 km^2, 2.14 km^2, and 7.53 km^2, respectively. Similarly, the river area displayed changes of -0.04 km^2, 0.02 km^2, -0.24 km^2, and -0.26 km^2 within the same time intervals. Furthermore, the study examined the impacts of LULC changes on water resources in this catchment by studying the morphology dynamics of the wetland and river during the same time period, using the same images for consistency. The Soetendalsvlei wetland channel was observed to constrict, especially its southern section, due to the expansion of reeds on its western bank and inside the channel. The Heuningnes river channel exhibited instability in its middle and lower portions, with the river mouth constantly changing its shape and shifting from 1990 to 2020. To assess the accuracy of LULC classification and the extraction of water bodies, the overall accuracy was determined to be 87%, 89%, 86%, and 94% for the years 1990, 2015, 2017, and 2020, respectively. As for wetland classification, the overall accuracy was found to be 98.18%, 94.55%, 92.73%, and

92.73% for the years 1990, 2015, 2017, and 2020, respectively. Regarding river classification, the overall accuracy was recorded as 87.06%, 77.65%, 81.18%, and 78.82% for the entire period from 1990 to 2020. The findings of this study demonstrate the usefulness of geospatial techniques in assessment of LULC changes impacts on water resources to provide valuable information for restoration and rehabilitation of degraded surface water resources.

Key words: Agriculture; land use and land cover; restoration and rehabilitation; water resources.

DECLARATION

I, Yamkela Mbambi declare that '**An assessment of river and wetland morphology dynamics using geospatial techniques**' is my own work, that it has not been submitted for any degree or examination in any other University, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Full name : Yamkela Mbambi

Signature : ………………………..

Date : 27 July 2023

PUBLICATIONS AND MANUSCRIPTS

The following manuscripts have been submitted and are still at the stage for peer review.

Mbambi, Y., Dube, T and Shoko, C. An Assessment of River and WetlandMorphology Dynamics Using Geospatial Techniques. [under peer review]

Mbambi, Y., Dube, T and Shoko, C. Mapping and Assessing Land Use and Land Cover Changes in the Heuningnes Catchment, South Africa: A Remote Sensing Approach to Understanding the Impacts on Water Resources Submission Currently in the Submission stage. Available at: https://watersa.net/submissions [under peer review]

ACKNOWLEDGEMENTS

I would like to thank, express my appreciation and gratitude to my supervisor Prof Timothy Dube for his support and guidance even at times I felt like not doing my work. Through your encouragement and assistance, I would like to say that you have made me a better person in life. Once again thank you for your patience.

I would also like to extend my appreciation to Dr Cletah Shoko for her constructive comments and support.

I also acknowledge the National Research Fund (NRF) bursary for its financial support during the years of my study.

I would like to also thank the University of the Western Cape for granting me the opportunity to further my studies.

The completion of this study could not have been possible without support from my family, especially from my mother Miss NE Mbambi. She was always there for me during the ups and downs of my academic journey. Finally, I would like to acknowledge my colleges and friends inside and outside the earth science department for availing themselves during times when I needed them.

So much love and respect to all those who helped in completion of this study.

Thank you

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

1.1 Introduction

Anthropogenic-attributed land use and land cover (LULC) changes have emerged as a significant environmental concern for researchers in various scientific fields, such as geomorphologists, ecologists, hydrologists, and others. These changes often lead to adverse impacts on the environment, ecosystems, climate, water availability, and food security (Chang et al., 2018; Molotoks et al., 2021; Winkler et al., 2021; Liu et al., 2023). Although land surface modification for resource consumption has been practiced for millennia to sustain life (Guppy and Anderson, 2017), the consequences of current land surface modifications are sometimes disregarded, leading to potential future concerns. For instance, planting vegetation to stabilize sand dunes in a particular area may inadvertently result in its overgrowth and encroachment on nearby water resources.

The pace of LULC changes has accelerated due to population growth and economic development (Addae and Oppelt, 2019; Marques et al., 2019; Alam et al., 2020), necessitating careful examination of their significant influences on water resources and their ecosystems. Anthropogenic-attributed LULC changes interact with water resources' morphological dynamics at various spatial and temporal scales (Baustian et al., 2018; Fashae et al., 2022). Consequently, changes in the area and morphology of water resources can impact their storage capacities, water supply, water ecosystems, and aquatic life. To address these challenges, monitoring LULC changes becomes essential to facilitate proper planning and effective management of water resources.

The relationship between LULC changes and the morphology dynamics and area changes of water resources is influenced by alterations in sediment loads supplied to water bodies following changes in land surface (Boota et al., 2021; Kayitesi et al., 2022). Neglecting LULC changes can exacerbate pressures and impacts on water resources, potentially leading to the loss of surface water bodies. The changing earth's surface has resulted in water shortages and security concerns at national and global levels (Kang and Kanniah, 2022), particularly affecting countries like South Africa, with limited water resources and facing rising temperatures due to global warming. Given South Africa's semi-arid region and economic challenges, continuous monitoring of LULC changes' impacts on water bodies is necessary to address and mitigate their impacts before they become uncontrollable.

Morphology dynamics and area changes of water resources occur due to interactions between flows and sediment loads (Bertagni et al., 2018). The modifications in water resource areas and shapes are influenced by the detachment and redistribution of sediments within channels or banks as flows change. The effects of different LULCs on area and morphology dynamics vary. For example, converting forests to agricultural lands increases sediment supply, leading to aggradation and changes in water resource size and shape. Similarly, vegetation invading bare land can affect morphology dynamics and area changes through flow and sediment load manipulation and direct occupation of water resources.

To examine the impacts of LULC changes on water resources' morphology dynamics and area changes in the Heuningnes catchment, remote sensing and Geographic Information Systems (GIS) are useful tools. These techniques have proven effective and reliable in resolving environmental and water-related issues. Combining remote sensing with GIS allows for timely data accessibility and ease of modification, making it a robust approach for change detection studies (Lu et al., 2004). The integration of remote sensing and GIS with field observations in this study is appropriate for providing valuable information for management strategies. It enables investigation into how water resource shapes and sizes change concerning changes in LULC within the catchment.

1.2 Aim and objectives

The aim of the study was to assess the LULC changes of the Heuningnes catchment and to detect their impacts on surface water resources.

Objectives were:

- To identify the primary LULC classes associated with area and morphology changes of water resources in this catchment.
- To examine the morphological dynamics and evolutions of the Soetendalvlei wetland and Heuningnes river from 1990 to 2020.

1.3 Conceptual framework

Figure 1 demonstrates the conceptual framework of the entire study. Objective 1 of the study was proposed to investigate how Heuningnes catchment's LULC changes influence the area changes of its water bodies. Of which Objective 2 was formulated to study the morphology dynamics of the Soetendalsvlei wetland and Heuningnes river, which are some of the major water resources in the catchment. The second objective was executed to support the findings from first objective and to serve evidence of how really the LULC changes contribute to morphology and area changes of the water bodies within the catchment.

The entire study was conducted using remote sensing data and GIS techniques. Supervised classification using the maximum likelihood approach was implemented for LULC change detection. For morphology dynamics spectral indexing using MNDWI and on-screen manual digitization methods were used to extract water bodies for analysis.

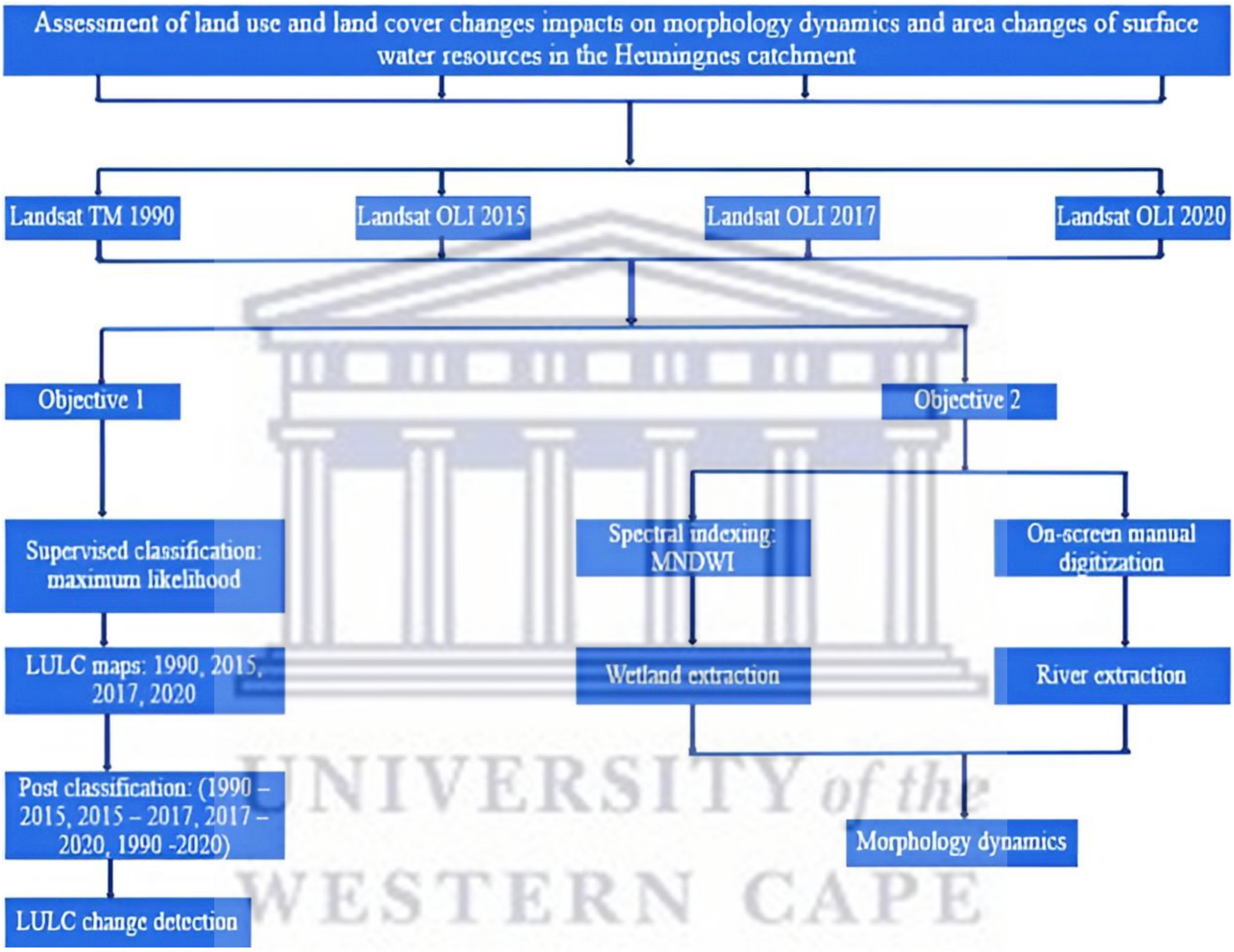

Figure 1. conceptual framework of the study.

1.4 Significance of the study

Knowledge about impacts induced by LULC changes on water resources is essential as it provides pre-requisite information to relevant stakeholders or governing bodies for establishing mitigation approaches and to gain insights that would assist in the development of adaptive measures for adversely affected water resources. LULC changes influences on morphology and sizes of water resources have impact on their storage capacities and water availability; hence the study can also be vital for development of conservation strategies. Additionally, improved knowledge about morphological dynamics of water resources provides information about parts of the river or wetlands that might require possible restoration and rehabilitation.

1.5 Thesis outline

Overview of the thesis structure

The whole thesis structure consists of four chapters including two isolate manuscripts to cover the first and the second objective of the study. Chapter 1 is the introduction section. Chapters 2 and 3 are the isolate manuscripts, and Chapter 4 is the final section of the study.

1.5.1 Chapter 1

Chapter 1 introduces the study by providing the background, objectives, and aim of the study. This chapter also covers the explanation for significance of this study. Lastly, at the end the chapter provides framework for the entire study.

1.5.2 Chapter 2

Chapter 2 of the study is an isolate manuscript that investigates the LULC changes in the Heuningnes catchment. The objective of this chapter was to cover the first objective of the study i.e., to determine the main LULC classes that can be associated with area and morphology changes of water resources in the catchment. Three LULC classes were investigated in relation to area changes for water body class, these LULC classes are bare land, vegetation, and agriculture class. Their spatial distribution changes were studied through analysis of the classified maps for different years from 1990 to 2020. The LULC classes area trends were correlated with area trends for water body class to discover their relationships or links with water body class. Thereafter the knowledge was gained about what LULC classes area changes influence the area changes of the water body class in the catchment, two water bodies (Soetendalsvlei wetland and Heuningnes river) were selected to further elucidate how LULC changes influence their morphology dynamics.

1.5.3 Chapter 3

Chapter 3 is another isolate manuscript which was intended to study the Soetendalsvlei wetland and Heuningnes river morphological dynamics for the same study period of the LULC change detection manuscript. The use of same period in these two manuscripts was to ensure consistency and integrity of the results. Spectral indexing (MNDWI) was used to extract wetland water features and manual on-screen digitization was implemented to extract water features (or polygons) for the river.

1.5.4 Chapter 4

This part of the study discusses the findings of the study and also gives the reached conclusions.

References

Addae, B., & Oppelt, N. (2019). Land-use/land-cover change analysis and urban growth modelling in the Greater Accra Metropolitan Area (GAMA), Ghana. *Urban Science*, *3*(1), 26.

Alam, A., Bhat, M. S., & Maheen, M. (2020). Using Landsat satellite data for assessing theland use and land cover change in Kashmir valley. *GeoJournal*, *85*, 1529-1543.

Baustian, M. M., Meselhe, E., Jung, H., Sadid, K., Duke-Sylvester, S. M., Visser, J. M., ... & Bargu, S. (2018). Development of an Integrated Biophysical Model to represent morphological and ecological processes in a changing deltaic and coastal ecosystem. *Environmental Modelling & Software*, *109*, 402-419.

Bertagni, M. B., Perona, P., & Camporeale, C. (2018). Parametric transitions between bare and vegetated states in water-driven patterns. *Proceedings of the National Academy of Sciences*, *115*(32), 8125-8130.

Boota, M. W., Yan, C., Idrees, M. B., Li, Z., Soomro, S. E. H., Dou, M., ... & Yousaf, A. (2021). Assessment of the morphological trends and sediment dynamics in the Indus River, Pakistan. *Journal of Water and Climate Change*, *12*(7), 3082-3098.

Chang, Y., Hou, K., Li, X., Zhang, Y., & Chen, P. (2018, February). Review of land use and land cover change research progress. In *IOP Conference Series: Earth and Environmental Science* (Vol. 113, p. 012087). IOP Publishing.

Fashae, O., Obateru, R., Olusola, A., & Dragovich, D. (2022). Factors controlling gully morphology on the quartzite ridges of Ibadan, Nigeria. *Catena*, *212*, 106127.

Guppy, L., & Anderson, K. (2017). Water crisis report. *United Nations University Institute for Water: Hamilton, ON, Canada*.

Kang, C. S., & Kanniah, K. D. (2022). Land use and land cover change and its impact on river morphology in Johor River Basin, Malaysia. *Journal of Hydrology: Regional Studies*, *41*, 101072.

Kayitesi, N. M., Guzha, A. C., & Mariethoz, G. (2022). Impacts of land use land cover change and climate change on river hydro-morphology-a review of research studies in tropical regions. *Journal of Hydrology*, 128702.

Kuenzer, C., Dech, S., & Wagner, W. (2015). *Remote sensing time series revealing land surface dynamics: Status quo and the pathway ahead* (pp. 1-24). Springer International Publishing.

Liu, B., Song, W., Meng, Z., & Liu, X. (2023). Review of Land Use Change Detection—AMethod Combining Machine Learning and Bibliometric Analysis. *Land*, *12*(5), 1050.

Lu, D., Mausel, P., Brondizio, E., & Moran, E. (2004). Change detection techniques. *International journal of remote sensing*, *25*(12), 2365-2401.

Marques, A., Martins, I. S., Kastner, T., Plutzar, C., Theurl, M. C., Eisenmenger, N., ... & Pereira, H. M. (2019). Increasing impacts of land use on biodiversity and carbon sequestration driven by population and economic growth. *Nature ecology & evolution*, *3*(4), 628-637.

Molotoks, A., Smith, P., & Dawson, T. P. (2021). Impacts of land use, population, and climate change on global food security. *Food and Energy Security*, *10*(1), e261.

Steffen, W., Sanderson, R. A., Tyson, P. D., Jäger, J., Matson, P. A., Moore III, B., ... & Wasson, R. J. (2005). *Global change and the earth system: a planet under pressure*. Springer Science & Business Media.

Winkler, K., Fuchs, R., Rounsevell, M., & Herold, M. (2021). Global land use changes are four times greater than previously estimated. *Nature communications*, *12*(1), 2501.

CHAPTER 2

Mapping and Assessing Land Use and Land Cover Changes in the Heuningnes Catchment, South Africa: A Remote Sensing Approach to Understanding the Impacts on Water Resources

Yamkela Mbambi[a*], Timothy Dube [a], Cletah Shoko [c]

[a]Institute for Water Studies, University of the Western Cape, Bellville, Cape Town, South Africa

[c]Department of Geography, School of Geography, Archaeology and Environmental Studies, University of Witwatersrand, P Bag 3, 2050, Braamfontein, Johannesburg, South Africa

Abstract

In this chapter, we utilized the maximum likelihood algorithm and spectral band combinations of Landsat series data to improve the classification of land use and land cover (LULC) changes in the Heuningnes catchment, located in South Africa, during the period from 1990 to 2020. Our image selection process was based on the availability of cloud-free images. Subsequently, we examined the impact of observed LULC changes on the region's surface water resources. For the years 1990, 2015, 2017, and 2020, the overall accuracy of LULC classification was determined to be 87%, 89%, 86%, and 94%, respectively. We observed a decrease in vegetation cover, particularly in the northern parts of the catchment, with the exception of a significant increase in 2020, which was only observed in low-lying areas. Agriculture expanded both on sloped terrains and in low-lying flat areas, mainly in the north-western part of the catchment. The trends in the agriculture class area were found to oppose those of the water body class. Similarly, the vegetation cover area trend in 2020 contradicted the water body area trend, while the bare land area showed no significant correlation with water body area trends across all years. These findings indicate that the land use and land cover classes that predominantly influenced changes in the water body class were vegetation and agriculture. These classes exhibited opposing area trends compared to the water body class and expanded in areas with a concentration of water bodies.

Keywords: Agriculture; Land cover dynamics; Mapping; Satellite data; Water availability, Vegetation.

2.1 Introduction

Global land surface degradation has emerged as a significant environmental concern, with the land surface experiencing constant transformations. Factors such as climate variability, population growth, and economic expansion play pivotal roles in driving changes in land uses and land covers (LULC) (Roy and Roy, 2010; James et al., 2022). The detection of LULC changes has gained increasing importance in recent years due to the growing necessity for sustainable land management and environmental planning (Abd El-Kawy et al., 2011). Tew et al (2019) claim that the ability to monitor and track LULC changes over time provides valuable insights for decision-makers across various fields, including urban planning, agriculture, biodiversity conservation, and natural resource management. Provided the usefulness of LULC change detection studies, understanding the causes and consequences of LULC changes will facilitate the development of effective policies and strategies that promote sustainable land use practices while minimizing adverse environmental impacts (Mahandhar et al., 2009).

In essence, the detection of LULC changes plays a critical role in informing land use policies and sustainable development plans. Accurate information on environmental changes is vital as it enables stakeholders to make well-informed decisions that consider both ecological and socioeconomic factors (Yao et al., 2018). Furthermore, LULC change detection studies enable continuous monitoring of LULC dynamics, facilitating the identification of emerging trends and patterns that can aid in predicting future land transformations (Das 2009; Pelorosso et al., 2009). Additionally, LULC change detection can also be used to assess the impacts of climate change on diverse landscapes and ecosystems, which is crucial for developing adaptation and mitigation strategies (Chowdhury and Islam, 2022). Therefore, it is imperative to conduct ongoing LULC change detection to better comprehend the intricate relationship between human activities and the environment.

Limited research has been conducted on land use and land cover (LULC) changes in developing countries, primarily due to their geographical location and economic status (Wanget al., 2020). Wang et al. (2020) argue that LULC change studies are particularly lacking in remote countries or regions. This knowledge gap poses a significant concern for developing countries, as they often face greater vulnerability to the impacts of LULC changes due to limited resources and adaptive capacity. Moreover, the absence of LULC research in developing countries hinders the global understanding of land-use patterns and their implications for climate change, biodiversity, and ecosystem services. Therefore, it is crucial to address this knowledge gap by conducting more LULC studies in developing countries and remote regions. Analysing these studies can help researchers comprehend the effects of natural and human-induced factors on land use patterns and identify areas that require intervention.

Geographic Information Systems (GIS) and Remote Sensing technology have become indispensable tools in LULC change detection studies (Tewabe and Fentahun, 2020). These tools offer valuable information to resource managers and landscape planners interested in understanding landscape characteristics and changes. GIS and Remote Sensing enable cost-effective spatiotemporal change detection analysis over extended periods and within short timeframes. This is made possible by satellite sensors that provide continuous and timely remotely sensed data by orbiting the Earth. The motion of these sensors allows them to capture images from different dates, facilitating change detection analysis. These images, provided in digital format, are suitable for computer processing (Akbar et al., 2017). Leveraging GIS techniques, computer processing enables the detection, quantification, and mapping of LULC changes (Chen et al., 2005). GIS also offers a flexible environment for data collection, storage, and analysis related to LULC changes. Therefore, remote sensing and GIS were utilized for this study to provide appropriated LULC change detections.

However, it is important to consider several limitations when conducting LULC change detection studies. One limitation involves the potential for errors in image interpretation and classification (Lu et al., 2004). Additionally, the availability of remote sensing data is often constrained by factors such as timing and weather conditions. Insufficient or limited data can result in incomplete datasets, thus compromising the accuracy and reliability of LULC change detection analyses. Nonetheless, with the utilization of available data, LULC studies can still be conducted using GIS and remote sensing to bridge the gap in our global understanding of LULC changes and their impacts.

2.2 Materials and methods

2.2.1 Description of the study area

The Heuningnes catchment is located at the southernmost tip of the African continent in the Western Cape province of South Africa (shown in figure 2). It spans an area of 1,938 km^2 (Bickerton, 1984) and is situated between latitudes 34°19' S and 34°50' S, and longitudes 19°35' E and 20°18' E. This catchment is comprised of five quaternary catchments: G50B, G50C, G50D, G50E, and G50F. It boasts various types of water bodies, including rivers (Nuwejaars, Kars, and Heuningnes River), wetlands (Voelvlei and Soetendalsvlei), and seasonal pans (Southpan, Longpan, and Rondpan) (Kinoti, 2018). Within the catchment, six towns can be found, including inland towns such as Bredasdorp, Elim, and Napier, as well as coastal towns like Struisbaai, Cape Agulhas, and Molshoop (Mtengwana et al., 2020). Other land covers present in this catchment include natural lands, shrublands, bushlands, and grasslands (Russel and Impson, 2006). The primary land uses in the Heuningnes catchment, as reported by Mazvimavi (2018) and Mkunyana et al. (2018), consist of dryland crop cultivation (wheat, barley, and canola), vineyards, growth of indigenous plants, and livestock farming (cattle and sheep). Additionally, the Heuningnes catchment supports endemic plants and rare species, and there has been recent documentation of the invasion of alien plant species in the area (Mtengwana et al., 2020). The topography of the catchment varies from 0 to 835 meters above mean sea level (mamsl). The mountainous regions predominantly consist of quartzitic sandstones from the Table Mountain Group, while the middle parts around Elim town are characterized by siltstones, mudstones, and sandstones from the Bokkveld Group. The low-lying areas are mostly covered by loose shelly sands, basal conglomerate, and calcareous sands (Mokoena et al., 2020). The catchment falls within the Mediterranean climatic zone, with significant temperature fluctuations throughout the year. Average temperatures range from 10°C in winter to 28°C in summer (Ndlala and Dube, 2021). Mean annual rainfall varies from 455 mm near the coast to 650 mm per year in the mountainous regions (Kraaij et al., 2009).

The Heuningnes catchment was specifically chosen as the study site due to its ongoing degradation. This catchment encompasses a diverse range of land use and land cover (LULC) types (Russel and Impson, 2006; Kinoti, 2018). Reports indicate that alien plant invasion, especially in the riparian zones of water-related ecosystems, is a significant issue in this area (Mtengwana, 2020; Mazvimavi, 2018; Mkunyana et al., 2019). Additionally, the Heuningnes catchment experiences intensive agricultural activities. Located in a semi-arid region with limited water resources, it frequently faces dry spells. Therefore, monitoring the extent and changes of LULCs in this catchment area is vital for establishing baseline information to support sustainable management and preservation of its natural resources. These LULC changes have a direct impact on the morphology and dynamics of water resources through sediment supply and erosion (Cheunchum et al., 2020; Maab et al., 2021), thereby affecting water availability. Moreover, as the most scenic part of the Western Cape, the degradation of the Heuningnes catchment could potentially undermine its appeal as a tourist destination.

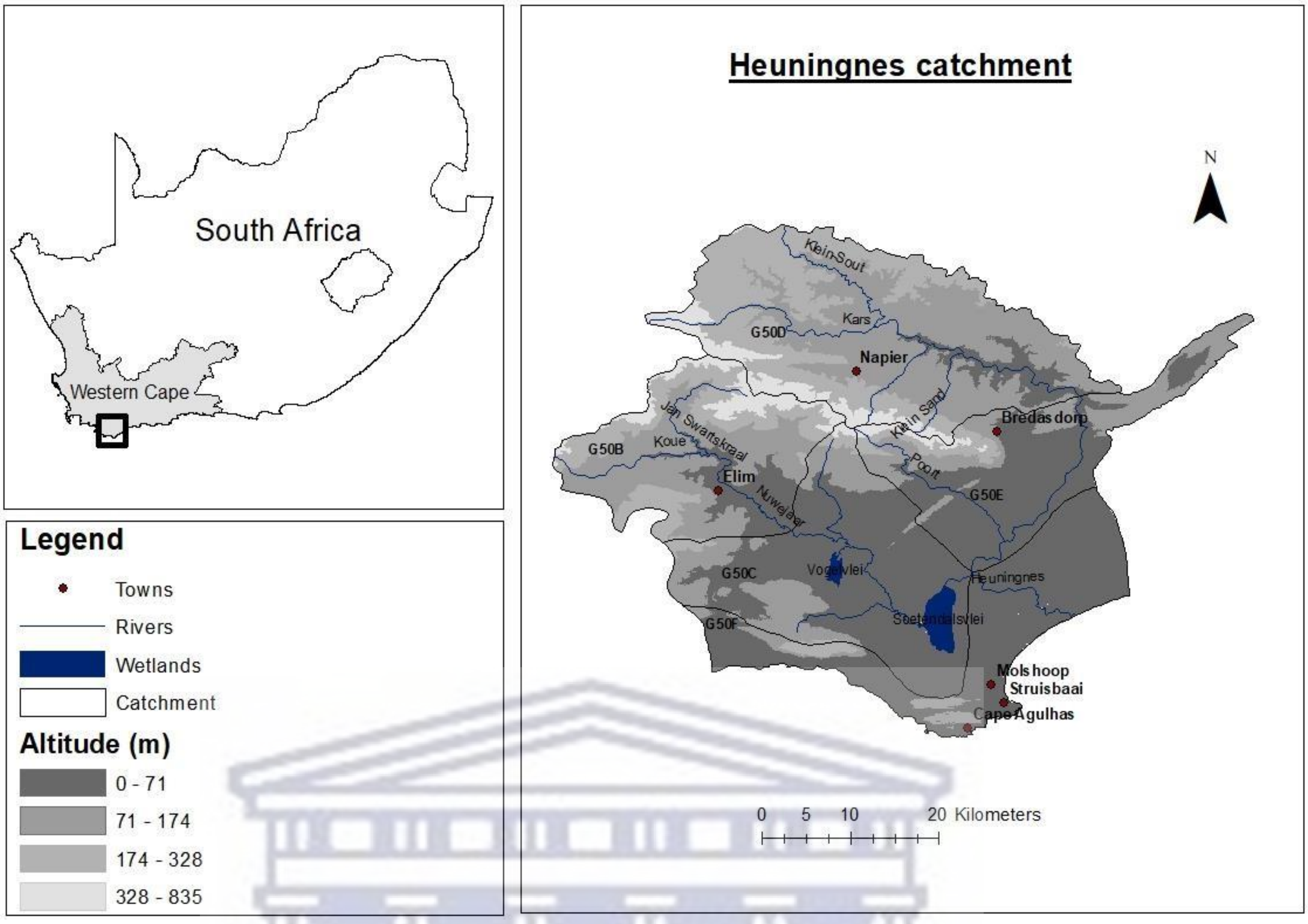

Figure 2. Location Map of the Heuningnes Catchment, South Africa

2.2.2 Acquisition of Satellite and Field Data

For the change detection analysis, four Landsat images were acquired. Among these, one image was captured by the Landsat TM sensor, while the remaining three images were captured by the Landsat OLI sensor. The Landsat TM image was obtained on February 27, 1990, while the Landsat OLI images were acquired on March 20, 2015, January 4, 2017, and April 2, 2020. All of these images had a spatial resolution of 30 meters per pixel. Importantly, the cloud cover in all these images was less than 1%, ensuring their suitability for conducting LULC change detection analysis.

2.2.3 Field data

In order to classify and validate land cover types obtained from satellite images, this study relied on the collection of ground truth data within the Heuningnes catchment during August 2018. A plot size of 30 m × 30 m was selected for gathering GPS locational data for individual land cover classes within each plot. This approach was based on previous studies in the literature that have utilized similar methodologies for vegetation mapping and related research. To record the locational data, the eTrex 10 Garmin GPS device was used, providing an error margin of 3.65 m (Garmin, 2019). Three hundred sixty-five ground truth points representing various land cover types were identified and recorded. To avoid oversampling, a minimum distance of 100 meters was maintained between GPS points. The observed vegetation classes were among the data collected for further analysis and classification.

2.2.4 Classification of Land Use and Land Cover Classes

Table 1 presents the spectral band combinations utilized in this study for mapping LULC changes in the study area. These band combinations were employed during image enhancement, where different combinations were applied to enhance specific classes, aiding in accurate sample identification. This approach, employed by previous studies (Butler, 2013; Erener, 2013; Chowdhury and Islam, 2022), has proven effective in optimizing both computer and practitioner capabilities in image classification. However, it should be noted that sample selection for this approach requires considerable time and computing expertise.

Table 1 also provides descriptions of the LULC classes relevant to this study. The table was adapted from the research conducted by Chowdhury and Islam (2022) and modified to provide clear explanations of the LULC classes in this particular study. In this study, the "water body" class refers to any waterlogged surface areas within the catchment that can be identified through image classification. The "bare land" class typically denotes open spaces devoid of vegetation, buildings, and water in most studies (Li et al., 2017; Chowdhury and Islam, 2022). However, in this study, the bare land class includes town coverage as well. This decision was made because bare lands with hardened surfaces exhibit similar impacts to built-up areas, influencing physical changes in water bodies, such as their area. These factors result in limitedsediment supply to rivers and wetlands, while increasing runoff and water supply, subsequently affecting the size of water bodies. It should be noted that the towns in the Heuningnes catchment are not extensive and are situated at a distance from regions concentrated with water bodies. Therefore, their impact on water bodies within this catchment is considered insignificant due to their small spatial coverage and proximity to water bodies. The vegetation class encompasses all plants found in the catchment, including alien plant species. The agriculture class specifically refers to farmlands and croplands within the study area.

Table 1. Spectral band combinations for Landsat TM and OLI sensors, as well as the LULC types and their descriptions. The table has been adapted from Butler (2013).

Composite	Landsat TM	Landsat OLI	Description
Built up	7 5 3	7 6 4	Residential and urban areas
Agriculture	5 4 1	6 5 2	Crop fields, vineyards, orchards, farmlands and cultivated areas.
Vegetation analysis	5 4 3	6 5 4	Forest, shrublands, grasslands, areas covered with alien invasive plants
Land / water	4 5 3	5 6 4	Open spaces, sand, rock covered areas, or streams, rivers, ponds, lakes, and wetlands

2.2.5 LULC Change Mapping

Figure 3 presents the procedural framework followed in this study for LULC change mapping. The Landsat images underwent pre-processing to correct for solar and atmospheric distortions. Since the images used were all from level 1 collection 1, which are already geometrically corrected and orthorectified, geometric correction was not included in this chapter. Atmospheric correction was performed in QGIS 2.18 using Dark Object Subtraction (DOS 1) to minimize atmospheric effects (Chavez, 1996). After the pre-processing stage, the images were imported into ArcGIS 10.3. Composite files were created for each year individually by utilizing the spectral bands. The composites were then clipped to focus on the study area, the Heuningnes catchment. Next, the clipped band composites underwent image enhancement using different spectral band combinations to improve the accuracy of LULC classification. The combinations of spectral bands were used to highlight and suppress specific LULC classes such as vegetation, water bodies, bare lands, and agriculture. To perform the classification, polygons were utilized to define representative LULC samples for each class. The supervised classification approach using the maximum likelihood method was implemented. This method is widely used as it considers the mean and covariance of each class and selects the most likely class among the candidates (Richards and Jia, 2006; Richards, 2022). It has been demonstrated to be effective across various cover types, conditions, and satellite systems (Lillesand and Kiefer, 2015; Richards, 2022). Different colours were assigned to represent different LULC classes in the resulting classified images. The post-classification method was employed to analyse the classified images. This method compares independently produced multi-temporal classified images to identify and indicate the nature of changes (Jensen, 2005; Yuan et al., 2005; Abd El-Kawy et al., 2011). It is recognized as an effective method for detecting changes and was used in this study. Finally, the classified images from different dates were intersected to generate LULC maps that illustrate the spatial changes in LULC covers within the catchment.

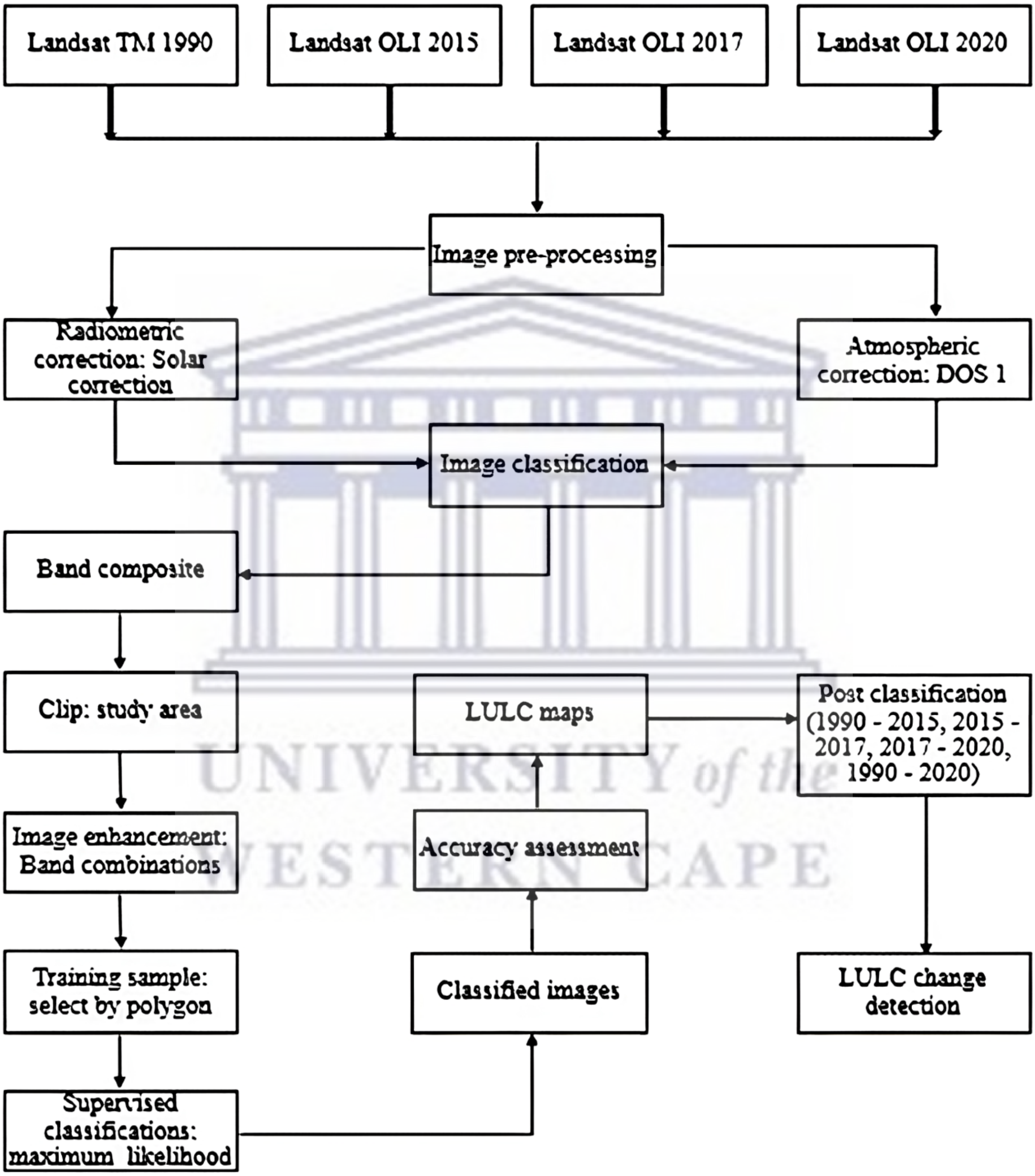

Figure 3. Procedural framework for the study.

2.3 Results

2.3.1 LULC Changes in the Heuningnes Catchment

Table 2 presents the extents of different LULC categories in the Heuningnes catchment, measured in terms of area and their percentage coverage relative to the catchment size. Based on the results in Table 2, water bodies occupy the smallest area within the catchment, followed by bare land. Water bodies cover 0.54% to 1.02% of the catchment, while bare land covers 10.72% to 21.41% between the years 1990 and 2020. Vegetation consistently covers approximately 30% to 50% of the catchment area. Agricultural lands range from close to 30% up to 46.48% in coverage.

Figure 4 illustrates that water bodies are predominantly located in the low-lying parts of the catchment. Bare land is scattered throughout the catchment, including coastal areas, urban regions, and other parts. Notably, bare land cover has increased in the northeast, around urban areas, and along the coastal line in the southeast. In this study, vegetation encompasses forests, shrublands, grasslands, and invasive alien plants, primarily covering the mountainous areas of the catchment and riparian zones of water-related ecosystems. Agricultural lands are mainly concentrated in the northwest and southeast parts of the catchment.

The bar graph (Figure 5) shows the area trends of each LULC class over the years of study. The bar graph demonstrates that when area of the agriculture class increases the area of water body class decreases, similarly vegetation opposed the area trend of water body class but only in 2020. While bare land class area trends show no link or relationships with water body class for all the years.

Figure 6 and Table 3 were generated using post-classification methods to illustrate the nature of changes and the extent of class area changes between the study years: 1990-2015, 2015-2017, 2017-2020, and 1990-2020. The maps in Figure 6 demonstrate that water bodies exhibit no significant changes in distribution but show variations in shape and size. The bare land class has expanded in coastal areas and around towns. Vegetation cover has gradually decreased in the northern parts of the catchment while remaining relatively stable in the low-lying areas. According to the results, agricultural lands have expanded in the north-western part and along the slopes leading to flat low-lying regions of the catchment.

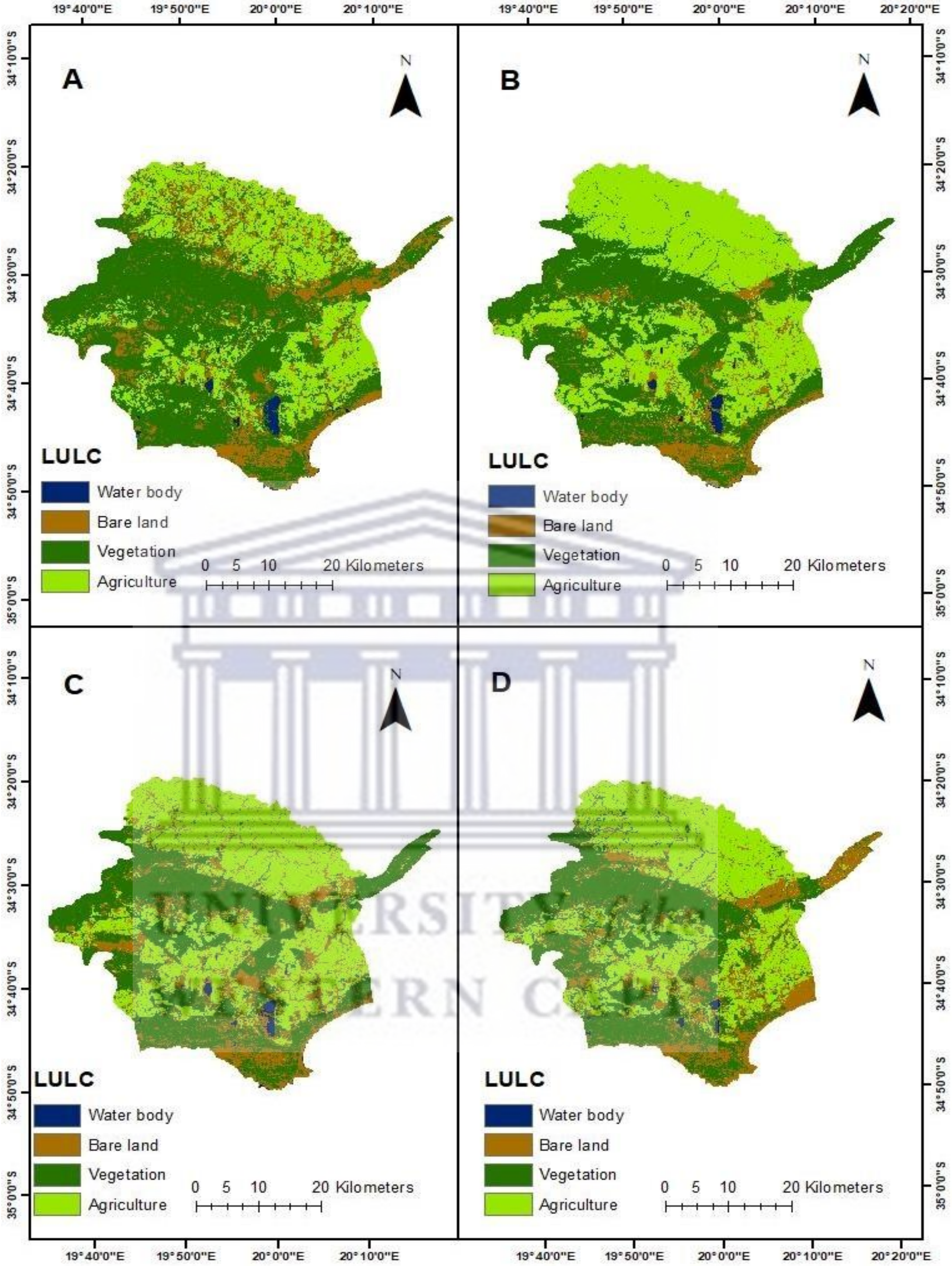

Figure 4. LULC Maps A, B, C, D for the Years 1990, 2015, 2017, and 2020 Respectively

Table 2. LULCs coverage extents from 1990 to 2020.

LULC class	1990		2015		2017		2020	
	Area(km^2)	%	Area(km^2)	%	Area(km^2)	%	Area(km^2)	%
Water body	19.76	1.02	14.95	0.77	15.39	0.79	10.57	0.54
Bare land	360.29	18.58	207.87	10.72	367.97	18.97	415.25	21.41
Vegetation	994.09	51.26	815.385	42.04	713.04	36.76	714.03	36.81
Agriculture	565.34	29.14	901.46	46.48	843.26	43.47	799.79	41.23

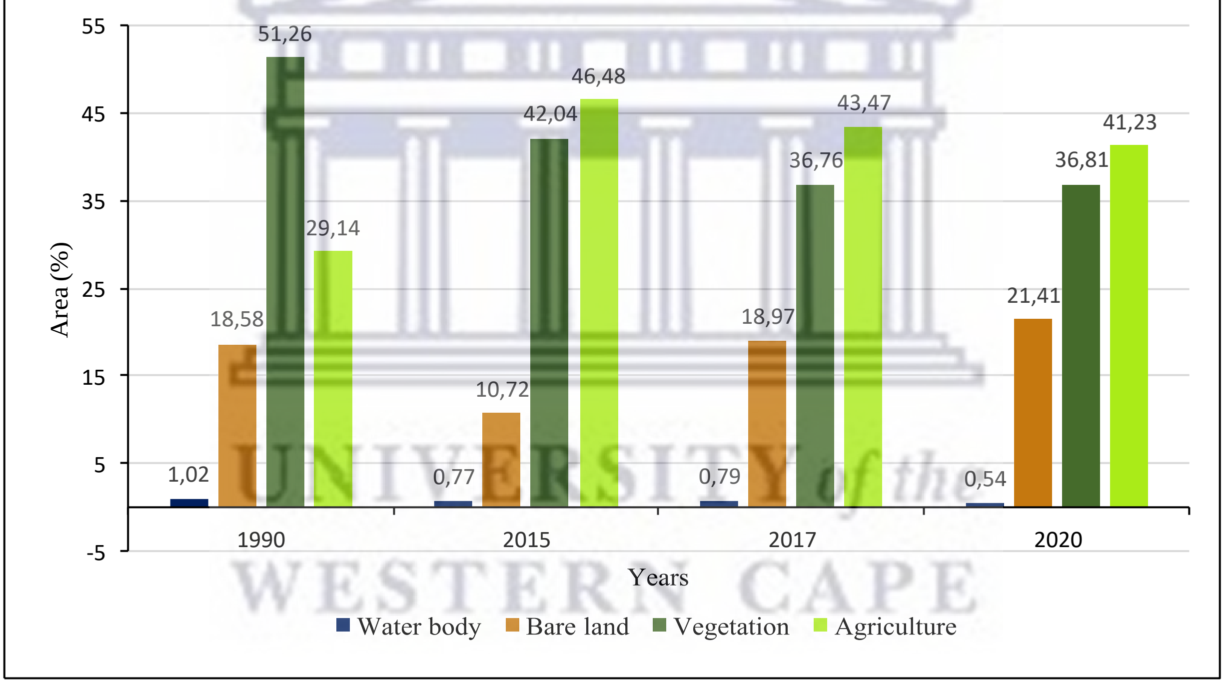

Figure 5. Bar graph illustrating the trends of LULC types throughout the study period.

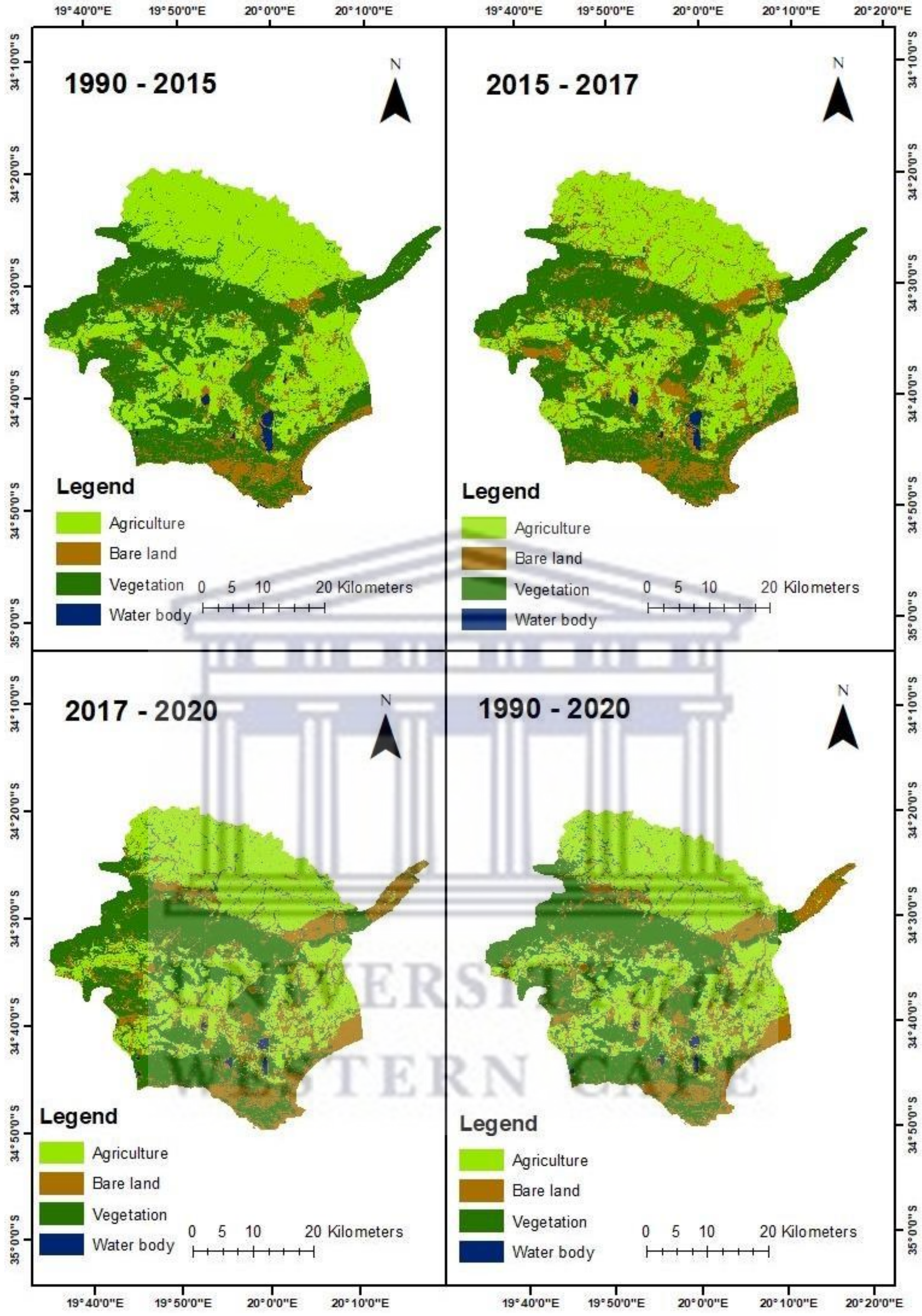

Figure 6. Changes in the spatial distribution of LULC classes.

Table 3. area changes of LULC classes for different time intervals.

LULC classes	Area (km^2) changes			
	1990 - 2015	2015 - 2017	2017 - 2020	1990 - 2020
Agriculture	336.12	-58.20	-43.47	234.45
Bare land	-152.42	160.10	47.28	54.96
Vegetation	-178.70	-102.35	0.99	-280.06
Water body	-4.81	0.44	-4.82	-9.19

2.3.2 Accuracy assessment

Tables 4 and 5 show the accuracy assessment metrices for LULC classifications of the Heuningnes catchment from different year images that were used in this study, starting from 1990 to 2020. The 1990 and 2015 classified images had overall accuracies of 87 % and 89 % respectively. Highest overall accuracy and kappa coefficient relative to other images were obtained from the 2020 image classification. The 2020 classified image generated overall accuracy of 94 % and kappa co-efficient of 0.92. The lowest overall accuracy and kappa co-efficient came from the classification of the 2017 image. Its overall accuracy was 86 % and kappa coefficient was 0.81.

Table 4. error matrix tables for classified images.

1990	**Water body**	**Bare land**	**Vegetation**	**Agriculture**	**Total**	**Commission error**
Water body	15	0	0	0	15	0.00%
Bare land	0	19	1	5	25	24.00%
Vegetation	0	0	24	6	30	20.00%
Agriculture	0	1	0	29	30	3.33%
Total	15	20	25	40	100	
Omission error	0.00%	5.00%	4.00%	27.50%		
2015	**Water body**	**Bare land**	**Vegetation**	**Agriculture**	**Total**	**Commission error**
Water body	13	0	2	0	15	13.33%
Bare land	0	22	0	3	25	12.00%
Vegetation	0	0	26	4	30	13.33%

Agriculture	0	1	1	28	30	6.67%
Total	13	23	29	35	100	
Omission error	0.00%	4.35%	10.34%	20.00%		
2017	**Water body**	**Bare land**	**Vegetation**	**Agriculture**	**Total**	**Commission error**
Water body	12	1	2	0	15	20.00%
Bare land	0	17	2	6	25	32.00%
Vegetation	0	3	27	0	30	10.00%
Agriculture	0	0	0	30	30	0.00%
Total	12	21	31	36	100	
Omission error	0.00%	19.05%	12.90%	16.67%		
2020	**Water body**	**Bare land**	**Vegetation**	**Agriculture**	**Total**	**Commission error**
Water body	15	0	0	0	15	0.00%
Bare land	2	19	0	4	25	24.00%
Vegetation	0	0	30	0	30	0.00%
Agriculture	0	0	0	30	30	0.00%
Total	17	19	30	34	100	
Omission error	11.76%	0.00%	0.00%	11.76%		

Table 5. Accuracy assessment of LULC classification for the 1990, 2015, 2017, and 2020 maps.

Year	Producer’s accuracy (%)				User’s accuracy (%)				Overall accuracy (%)	Kappa Coefficient
	Water body	Bare land	Vegetation	Agriculture	Water body	Bare land	Vegetation	Agriculture		
1990	100.00	95.00	96.00	72.50	100.00	76.00	80.00	96.67	87.00	0.82
2015	100.00	96.65	89.66	80.00	86.67	88.00	86.67	93.33	89.00	0.85
2017	100.00	80.95	87.10	83.33	80.00	68.00	90.00	100.00	86.00	0.81
2020	88.24	100.00	100.00	88.24	100.00	76.00	100.00	100.00	94.00	0.92

2.4 Discussion

This study employed the maximum likelihood algorithm and Landsat series data spectral band combinations to enhance image classification for mapping and assessing land use and land cover (LULC) changes in the Heuningnes catchment, South Africa (Richards and Jia, 2006; Richards, 2022). The primary objective was to investigate the LULC classes that significantly influence changes in water bodies within the catchment. The findings of this study demonstrate that the area or coverage extent of water body LULC class exhibits constant fluctuations over time.

From 1990 to 2015, the bare land LULC class experienced a decrease, followed by an increase in subsequent years (2015, 2017, and 2020). This pattern can be attributed to the conversion of open spaces to agricultural lands during the initial period. The subsequent increase in bare land can be attributed to the expansion of urban areas such as Elim, Bredasdorp, Cape Agulhas, and Napier, as urban areas were included in the bare land class (DEAP, 2011). The Western Cape province witnessed a significant population influx after the political shift in 1994, resulting in increased urban development and land use activities along the southern coastal region. It is anticipated that urban areas will continue expanding due to population growth. Currently, all the towns in the Heuningnes catchment rely on springs and boreholes for their water supply, which implies that their impact on surface water bodies is limited as they do not directly extract water from them (Clarke et al., 2018). Furthermore, these towns are situated at a distance from surface water bodies and are not extensive, which minimizes their impact on the size of surface water bodies. The expansion of bare land may also be influenced by misclassifications where cultivated agricultural lands are mistaken for bare land. However, the accuracy assessment validated that very few agricultural lands were misclassified as bare land.

The vegetation cover class exhibited a decreasing trend in the northern parts of the catchment area, while it remained relatively unchanged in the low-lying parts. The vegetation class decreased from 1990 to 2015 and 2017, with a slight increase observed in 2020. In the low-lying areas, the expansion of vegetation was observed, particularly near the Soetendalsvlei wetland, while the Soetendalsvlei southern section experienced a significant reduction in size. These findings support claims made by Mazvimavi (2018) and Mkunyana et al. (2019) regarding the presence of vegetation in riparian zones of water-related ecosystems and mountainous regions within the Heuningnes catchment (Mtengwana, 2020). Clarke et al. (2018) argued that invasive alien plants in the catchment lead to reduced water availability in water bodies due to increased evaporation, transpiration, and interception losses compared to indigenous vegetation. Additionally, the mean annual runoff of the Heuningnes estuary, previously predicted to be 32.39 million m^3, has decreased to 27.35 million m^3 primarily due to the invasion of alien plants (Clarke et al., 2018). In summary, the presence of vegetation, especially invasive alien plants, has a significant impact on water availability in the water resources of the catchment, aligning with the findings of this study that the vegetation class is one of the major LULCs influencing changes in the water class.

Contrary to the trend observed for water bodies, agriculture exhibited a trend that contradicted it. When water body sizes and spatial coverage increased, agriculture decreased during the years 1990, 2015, and 2017. The Department of Environmental Affairs and Planning (DEAP) (2011) stated that dry crop lands, orchards, and vineyards are major land uses within the catchment. Agricultural activities such as cultivation, tilling, animal grazing, and water extraction for drinking purposes contribute to increased sediment supply to water bodies. Barasa et al. (2017) highlighted that the increased sediment supply from agricultural lands leads to channel aggradation and degradation in water bodies. Moreover, water consumption for livestock and irrigation purposes reduces the availability of water in water bodies. Therefore, the expansion of agricultural lands corresponds to increased water consumption and sediment supply to water bodies, resulting in a decrease in the area of water body class. This aggradation of water bodies also creates a favorable environment for vegetation growth, further reducing their size. To protect, preserve, and sustain water bodies within the catchment, agriculture is one of the LULC classes that requires significant attention to mitigate its impact. During this study, some misclassifications occurred, where a few agricultural lands with intense plantations were mistaken for vegetation or bare land, but these were identified and validated during the accuracy assessment.

2.4.1 Implications of land use and land cover changes on water resources

The implications of land use and land cover changes, as well as the occurrence of invasive species, have far-reaching consequences for water resources, water security, food security, ecosystem health, and the effectiveness of initiatives such as the South African Working for Water Programme in semi-arid environments. These regions often face the challenge of water scarcity, and when land use changes occur, such as urbanization or the expansion of agriculture, the pressure on water resources intensifies, directly impacting SDG 6 (Clean Water and Sanitation) and water security (UN, 2015). In semi-arid environments, invasive species can exacerbate the water scarcity issue. These species, often thriving in disturbed habitats, have the ability to outcompete native vegetation, altering the natural hydrological cycle. They can consume excessive amounts of water, reducing water availability for other uses, and even exacerbate soil erosion, leading to sedimentation and the degradation of water quality (D'Antonio and Vitousek, 1992). Consequently, the presence of invasive species poses a significant challenge to achieving SDG 6, as it hampers efforts to ensure clean and sustainable water sources.

Furthermore, the impacts of land use changes and invasive species extend beyond water resources. The agricultural sector, a vital component of food security (SDG 2: Zero Hunger), can be severely affected. Invasive species can compete with crops for resources, reducing agricultural productivity and threatening food production (FAO, 2001). As a result, the presence of invasive species can undermine efforts to ensure access to safe, nutritious, and sufficient food for all.

Ecosystem health is also greatly affected by land use changes and the spread of invasive species in semi-arid environments. Invasive species can disrupt the natural balance of ecosystems, leading to the loss of native plant and animal species. This loss of biodiversity directly conflicts with SDG 15 (Life on Land) and hampers the conservation and sustainable use of terrestrial ecosystems (CBD, 2002). Ecosystems play a crucial role in maintaining water quality, regulating water flow, and providing various ecosystem services, making their health and resilience critical for water resources and overall environmental sustainability. Recognizing the interconnectedness of these challenges, the South African Working for Water Programme plays a vital role in addressing the impact of invasive species and restoring ecosystem functionality. By implementing sustainable land management practices and prioritizing water conservation efforts, this program aligns with multiple SDGs, contributing to the overall resilience and sustainability of semi-arid environments. It aims to protect water resources, promote water security, enhance agricultural productivity, safeguard ecosystem health, and support the broader goals of sustainable development (DWAF, 1995). In conclusion, the implications of land use and land cover changes, invasive species occurrence, and the subsequent effects on water resources in semi-arid environments are significant and multi-faceted. They directly affect water security, food security, ecosystem health, and the success of initiatives such as the South African Working for Water Programme. Addressing these challenges requires integrated approaches that prioritize sustainable land management, invasive species control, water conservation, and the preservation of ecosystem integrity. By doing so, we can work towards achieving the SDGs, ensuring the availability of clean water, promoting food security, preserving biodiversity and building resilient and sustainable communities in semi-arid environments.

2.5 Conclusion

The primary aim of this chapter was to examine the relationship between land use and land cover (LULC) classes and changes in the area of water bodies in the Heuningnes catchment. The researchers compared the changes in the area of water body LULC class with other LULC classes, including bare land, vegetation, and agriculture. The findings indicated that vegetation cover is consistently decreasing in the northern parts of the catchment, while remaining relatively stable in the low-lying areas. Only in 2017 and 2020 was there an observed increase in vegetation coverage extent. In 2020, the water body class covered the minimum extent of the catchment, accounting for only 0.54% (10.57 km2). During this period, the only LULC classes that showed an increase were vegetation and bare land. However, the changes in bare land did not significantly affect the water body class. Thus, it can be inferred that vegetation was the primary driver of changes in the water body class in 2020. Contrary to the changes observed in the water body class, the area changes in agricultural land contradicted those of the water body class for all years. Increases in the coverage extent of agricultural lands were accompanied by decreases in the coverage extent of the water body class. Consequently, agriculture and vegetation emerged as the main LULC classes that demonstrated significant impacts on changes in the area of the water body class. In conclusion, this study highlights the influence of agriculture and vegetation on changes in the area of water bodies in the Heuningnes catchment. The findings indicate that vegetation is the key driver of changes in the water body class, while agricultural land exhibits a contrasting relationship.

2.6 Recommendations

Following are the recommendations to ensure high quality results are obtained from LULC change detection studies when utilizing the supervised classification method:

- During the classification step, the user is recommended to select as many representative samples as possible for each LULC class. This is because the image classification software (e.g., ArcGIS) uses the training sites (samples) to determine all the LULC classes in the full image. Therefore, selection of many samples increases the accuracy of classifications and reliability of the classified images.
- Additionally, it is also advised to select samples across the entire image, instead of concentrating in one area of the image and select samples that are big enough, to

improve the feasibility of other similar samples for each class to be identified by the software. This owes to the fact that digital image classification identifies class based on what it most closely resembles in the training set.

- The user is advised to also have improved knowledge or familiarity with the study site to be classified. Knowledge of where certain land covers are in the image improves the chances of correct classification.

Based on the results of this study, the above-mentioned recommendations were established to support and ensure high accuracy and reliability of LULC change detection studies in the future.

References

Abd El-Kawy, O. R., Rød, J. K., Ismail, H. A., & Suliman, A. S. (2011). Land use and land cover change detection in the western Nile delta of Egypt using remote sensing data. *Applied geography*, *31*(2), 483-494.

Akbar, M. S., Sarker, M. H., Sattar, M. A., Sarwar, G. M., Rahman, S. M. M., Rahman, M. M., & Khan, Z. U. (2017). Integrated use of remote sensing, GIS and GPS technology for monitoring the environmental problem of Shyamnagar. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *42*, 357-364.

Barasa, B., Kakembo, V., Mwololo Waema, T., & Laban, M. (2017). Effects of heterogeneous land use/cover types on river channel morphology in the Solo River catchment, Eastern Uganda. *Geocarto International*, *32*(2), 155-166.

Bickerton, I. B. (1984). *Heuningnes (CSW19)*. CSIR, National Research Institute for Oceanology.

Butler, K. (2013). Band combinations for Landsat 8. *ArcGIS blog Esri*.

CBD (Convention on Biological Diversity). (2002). Global Strategy for Plant Conservation. Retrieved from https://www.cbd.int/gspc/

Chavez. P. S, (1996). Image-based atmospheric corrections-revisited and improved. *Photogrammetric engineering and remote sensing*. *62*(9). 1025-1035.

Chen, X., Vierling, L., & Deering, D. (2005). A simple and effective radiometric correction method to improve landscape change detection across sensors and across time. *Remote Sensing of Environment*, *98*(1), 63-79.

Chowdhury. T. A., & Islam. M. S, (2022). Assessing and simulating impacts of land use land cover changes on land surface temperature in Mymensingh City. Bangladesh: 10.32526/ennrj/20/202100110. *Environment and Natural Resources Journal*. *20*(2). 110-128.

Chuenchum, P., Xu, M., & Tang, W. (2020). Predicted trends of soil erosion and sediment yield from future land use and climate change scenarios in the Lancang–Mekong River by using the modified RUSLE model. *International Soil and Water Conservation Research*, *8*(3), 213-227.

Clark, B. M., Van Niekerk, L., & Turpie, J. (Eds.). (2018). Determination of the Ecological Water Requirements for the Heuningnes.

D'Antonio, C. M., & Vitousek, P. M. (1992). Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics, 23(1), 63-87.

Das, T. (2009). *Land use/Land cover change detection: An object oriented approach, Münster, Germany* (Doctoral dissertation).

DEAP, W. C. I. W. R. (2011). Management (IWRM) Action Plan: Status Quo Report Final Draft. *Provincial Government, Department of Environmental Affairs and Development Planning, South Africa*.

Dube, T., & Ndlala, N. (2021). Use of remotely sensed derived metrics to assess wetland vegetation responses to climate variability-induced drought at the Soetendalsvlei wetland system in the Heuningnes Catchment, Western Cape province, South Africa.

DWAF (Department of Water Affairs and Forestry). (1995). Working for Water Programme. Retrieved from https://www.environment.gov.za/projectsprogrammes/workingforwater.

Erener, A. (2013). Classification method, spectral diversity, band combination and accuracy assessment evaluation for urban feature detection. *International Journal of Applied Earth Observation and Geoinformation, 21*, 397-408.

FAO (Food and Agriculture Organization). (2001). The state of food and agriculture: Agricultural trade and poverty: Can trade work for the poor? Retrieved from http://www.fao.org/3/y4671e/y4671e00.htm

Garmin, 2019. *ETREX 10/20/20X/30/30X Owner's Manual*. Olathe, KS.

James, L. A., Lecce, S. A., & Pavlowsky, R. T. (2022). Impacts of land-use and land-cover change on river systems.

Jensen, J. R. (2005). Digital image processing: a remote sensing perspective. *Upper Saddle River, NJ: sPrentice Hall*.

Kinoti, I. K. (2018). *Integraded hydrological modeling of surface and groundwater interactions in Heuningnes catchment (South Africa)* (Master's thesis, University of Twente).

Kraaij, T., Hanekom, N., Russell, I. A., & Randall, R. M. (2009). Agulhas National Park State of Knowledge. *Unpublished Internal Report, South African National Parks, 51*.

Li, H., Wang, C., Zhong, C., Su, A., Xiong, C., Wang, J., & Liu, J. (2017). Mapping urban bare land automatically from Landsat imagery with a simple index. *Remote sensing*, *9*(3), 249.

Lillesand, T., Kiefer, R. W., & Chipman, J. (2015). *Remote sensing and image interpretation*. John Wiley & Sons.

Lu, D., Mausel, P., Brondizio, E., & Moran, E. (2004). Change detection techniques. *International journal of remote sensing*, *25*(12), 2365-2401.

Maaß, A. L., Schüttrumpf, H., & Lehmkuhl, F. (2021). Human impact on fluvial systems in Europe with special regard to today's river restorations. *Environmental Sciences Europe*, *33*, 1-13.

Manandhar, R., Odeh, I. O., & Ancev, T. (2009). Improving the accuracy of land use and land cover classification of Landsat data using post-classification enhancement. *Remote Sensing*, *1*(3), 330-344.

Mazvimavi. D, (2018). Finding "new" water to address conflicting and competing water demands in the Nuwejaars Catchment. Cape Agulhas. *Water Research Commission Report. Pretoria.*

Mkunyana. Y. P., Mazvimavi. D., Dzikiti. S., & Ntshidi. Z, (2019). A comparative assessment of water use by Acacia longifolia invasions occurring on hillslopes and riparian zones in the Cape Agulhas region of South Africa. *Physics and Chemistry of the Earth. Parts A/B/C. 112*. 255-264.

Mokoena, P., Kanyerere, T., & van Bever Donker, J. (2020). Hydrogeochemical characteristics and evaluation of groundwater quality for domestic and irrigation purposes: A case study of the Heuningnes Catchment, Western Cape Province, South Africa. *SN Applied Sciences*, *2*(9), 1548.

Mtengwana. B, (2020). Spatial modelling of invasive species distribution in water-limited environments using remotely sensed data and climatic scenarios in the Heuningnes catchment, South Africa.

Pelorosso, R., Leone, A., & Boccia, L. (2009). Land cover and land use change in the Italian central Apennines: A comparison of assessment methods. *Applied geography*, *29*(1), 35-48.

Richards, J. A., & Jia, X. (2006). Multispectral transformations of image data. *Remote Sensing Digital Image Analysis: An Introduction*, 137-163.

Richards, J. A., & Richards, J. A. (2022). *Remote sensing digital image analysis* (Vol. 5). New York: springer.

Roy, P. S., & Roy, A. (2010). Land use and land cover change in India: Aremote sensing & GIS prespective. *Journal of the Indian Institute of Science*, *90*(4), 489-502.

Russell, I. A., & Impson, N. D. (2006). Aquatic systems in and adjacent to Agulhas National Park with particular reference to the fish fauna. *Koedoe*, *49*(2), 45-57.

Tew. Y. L., Tan. M. L., Samat. N. A. R. I. M. A. H., & Yang. X. I. A. O. Y. I. N. G. (2019). Urban expansion analysis using Landsat images in Penang. Malaysia. *Sains Malaysiana*. *48*(11). 2307-2315.

Tewabe, D., & Fentahun, T. (2020). Assessing land use and land cover change detection using remote sensing in the Lake Tana Basin, Northwest Ethiopia. *Cogent Environmental Science*, *6*(1), 1778998.

UN (United Nations). (2015). Sustainable Development Goals. Retrieved from https://sdgs.un.org/goals

Wang. S. W., Gebru. B. M., Lamchin. M., Kayastha. R. B., & Lee. W. K, (2020). Land use and land cover change detection and prediction in the Kathmandu district of Nepal using remote sensing and GIS. *Sustainability*. *12*(9). 3925.

Yao. Y., Chen. D., Chen. L., Wang. H., & Guan. Q. (2018). A time series of urban extent in China using DSMP/OLS nighttime light data. *PLoS One*. *13*(5). e0198189.

Yuan, F., Sawaya, K. E., Loeffelholz, B. C., & Bauer, M. E. (2005). Land cover classification and change analysis of the Twin Cities (Minnesota) Metropolitan Area by multitemporal Landsat remote sensing. *Remote sensing of Environment*, *98*(2-3), 317-328.

CHAPTER 3

Assessment of land use and land cover changes impacts on morphology and area changes of surface water resources in the Heuningnes catchment.

Yamkela Mbambi[a]. Timothy Dube [a]. Cletah Shoko [c]

[a]Institute for Water Studies, University of the Western Cape, Bellville. Cape Town. South Africa

[c]Department of Geography, School of Geography, Archaeology and Environmental Studies, University of Witwatersrand, P Bag 3, 2050, Braamfontein, Johannesburg, South Africa

Abstract

The degradation of surface water resources is an ongoing concern, primarily resulting from human interventions and activities. Without proper monitoring and care, these water resources may progressively lose their functionality. Therefore, it is crucial to gain a comprehensive understanding of their morphological dynamics, as they significantly impact water availability and the stream's power to execute geomorphic work. By studying and comprehending these dynamics, we can enhance the functionality of modified water bodies and ensure their long-term sustainability. The purpose of this work was to evaluate the morphological dynamics and evolution patterns of the Heuningnes River and Soetendalsvlei Wetland from 1990 to 2020, utilizing Geospatial techniques. This was accomplished through the mapping of changes in their shape (form) and the detection of alterations in their area. The analysis of the findings uncovered noteworthy modifications in the channels of Soetendalsvlei's southern and middle to lower sections (estuary). On the other hand, the channels of Soetendalsvlei's northern portion and the Heuningnes River remained unaltered in 1990, 2015, 2017, and 2020. However, in 2020, vegetation growth was observed within the channel of Soetendalsvlei's northern section. During the specified time intervals of 1990-2015, 2015-2017, 2017-2020, and 1990-2020, the wetland area experienced reductions of 4.06 km^2, 1.34 km^2, 2.14 km^2, and 7.53 km^2 respectively. On the other hand, the river area displayed changes of -0.04 km2, 0.02 km^2, -0.24 km2, and -0.26 km^2 within the same time intervals. The river area changes exhibited a fluctuating trend. In terms of classification accuracy, the overall accuracy for wetland classification was determined to be 98.18%, 94.55%, 92.73%, and 92.73% for the years 1990, 2015, 2017, and 2020 respectively. As for river classification, the overall accuracy was recorded as 87.06%, 77.65%, 81.18%, and 78.82% for the entire period from 1990 to 2020. These findings highlight the dynamic nature of wetland and river areas, emphasizing the importance of continuous monitoring and accurate classification for effective management and conservation efforts.

Keywords: Bankline shift; Channel adjustment; Management and conservation; morphology; River shape; Satellite data.

3.1 Introduction

River planform characteristics and sinuosity are well-known to be vital geomorphological parameters that control river flows and the energy of a river system to execute geomorphic processes (stream power), such as supply of sediments to downstream reaches. The need to monitor the river channel dynamics is helpful to understand the river evolution patterns and help in river planning and management, very crucial especially for lower reaches which remain poorly understood (Langat et al., 2019). While monitoring of wetland morphology dynamics is vital for flood and drought management (Alcántara-Ayala, 2002). Dallas et al (2006) stated that wetlands minimize the risk of flooding, help in groundwater recharge and aid in amelioration of water quality. The monitoring of wetland morphology dynamics does not only influence water storage capacity but also plays a crucial role in understanding water level fluctuations and flood events (Hayashi and van der Kamp, 2021). Additionally, Carolissen (2021) emphasized that investigations into wetland morphology contribute significantly to wetland classification and provide valuable insights into the physical characteristics of wetlands that impact ecological and hydrological processes. While Parry et al (2007) anticipated the wetlands to keep declining because of human impacts, climate change, and sea level rise. On the other hand, river spatiotemporal morphology dynamics studies assist in providing guidance to development of river infrastructures such as weirs and flumes, as to where (suitability in accordance to limiting destructions or failures) these should be situated along or within the river systems. Moreover, Kuo et al (2017) stated that the river channel migrations or shifts reflect the sensitivity of the valley floors and that determines the risk of nearby communities and infrastructure to damages. This is also supported by the recent study of Raj and Signh (2022); the study reported that bank line shifts pose a threat to engineering infrastructures, agricultural areas, and nearby dwelling communities. Monitoring of river channel form dynamics would also assist in management of sediment transport and vegetation on riparian zones with concerns of flood risk reduction (Boothroyd and Guerrero, 2021). Provided all these reasons, that shows the necessity for execution of water resources morphology dynamics studies to facilitate proper management.

The characterization of river and wetland morphological dynamics can be conducted through utilization of remote sensing and GIS (Guo et al., 2017). Remote sensing technology has been recognized to be extremely important throughout the years for supplying spatial information about the earth's surface (Jones and Reinke, 2009). The utilization of GIS techniques offers various methods for extracting water information from satellite images, with spectral indexing being one of them. Spectral indexing involves the utilization of multi-spectral bands to enhance water bodies and minimize non-water features. By capitalizing on the unique reflectance properties (spectral signatures) of features within satellite images, spectral indexes can be employed. These indexes exploit the differential radiometric energy reflectance exhibited by various features (Xu, 2006). For instance, the Modified Normalized Difference Water Index (MNDWI) leverages the green and shortwave infrared bands to effectively highlight water features while suppressing non-water features. The combination of remote sensing and GIS tools provides numerous advantages, as they enable rapid detection of environmental changes through the utilization of affordable, accessible, and freely available remotely sensed imagery and GIS analytical tools. The diverse spatial, spectral, and temporal resolutions offered by different satellites provide an extensive amount of data that serves as a primary resource for extracting surface water bodies and detecting changes over time. (Li et al., 2013; Tang et al., 2013). According to Bertrand et al. (2013) and Grabowski et al. (2014), remote sensing and GIS play a vital role in monitoring geomorphological changes at both reach and catchment scales. However, there appears to be a lesser emphasis on studying the channel morpho-dynamics of surface water resources. Many studies tend to focus more on mapping surface water bodies, assessing water quality, and understanding the factors influencing water quality, such as changes in land use and land cover (LULC). In light of this, the objective of this particular study was to examine the morphological dynamics of the Heuningnes River and Soetendalsvlei Wetland. By conducting this analysis, we aimed to fill the gap in research regarding the channel morpho-dynamics of these specific surface water resources.

3.2 Materials and methods

3.2.1 Study site description

The Soetendalsvlei wetland and Heuningnes river are located in Cape Agulhas region, in the Heuningnes catchment (Figure 7). These two water bodies are connected and are situated in flat low-lying terrain of the Heuningnes catchment. Soetendalsvlei wetland and Heuningnes river are only separated by a weir in their convergence. These two water bodies are recharged by Nuwejaars River, and the Heuningnes river is also connected to the Kars river (a tributary). The Heuningnes river debouches into Indian ocean forming estuary at Cape De Mond nature reserve.

The Soetendalsvlei wetland is represented by the letter A in figure 7. This wide, shallow wetland is in the Southern cape coast of South Africa (Gordon, 2012). The Soetendalsvlei wetland is one of the major water bodies in the Heuningnes catchment. According to Hoekstra and Waller (2014) this is the second biggest wetland in South Africa after the Chrissie wetland. These inflows are normally alkaline and brackish. Alkaline and brackish waters are the result of rivers flowing through limestone-bearing Strandveld sands and Bokkeveld shales (Noble and Hemens, 1978). Back-then before the existence of a weir between the Soetendalsvlei and the Heuningnes River, these freshwater bodies used to be connected. Clarke et al (2018) claimed that water flows from the Soetendalsvlei Wetland to Heuningnes River only during high-flow periods. The shape of the Soetendalsvlei wetland is defined by two waterbody sections (i.e., the Soetendalsvlei north and the south) separated by reeds. Fortune (2018) claimed that Soetendalsvlei wetland becomes a single waterbody when it is inundated only in years with high rainfall. This study site is approximately 8 km long and 3 km wide (Gordon et al, 2012; Ndlala and Dube, 2022). According to Noble and Hemens (1978) the Soetendalsvlei wetland has a water surface area that covers about 20 km^2 of spatial extent with the average water depth of 2 m. Due to the strong winds that blow in the area all year long, reed growth is only seen along the western shore (Gordon. 2012). The agricultural practices on the eastern shore and freshwater extraction from the Nuwejaars River are the main human-induced influences on the Soetendalsvlei wetland. Moreover, there is a deficit of fresh or brackish water exchange between Soetendalsvlei and the Heuningnes river and estuary because the artificial breach that keeps the estuary mouth permanently open and the existence of a weir where the river and the wetland merge (Clarke et al. 2018)

The Heuningnes river is formed from the excess water from the Soetendalsvlei wetland and Kars River (Clarke et al., 2018). The Heuningnes river is 15 km long including the estuary. According to van Niekerk et al (2020) an estuary is a partially enclosed permanent body of water that is open to the sea on a continuous or periodic basis and extends as far as the upper bound of tidal action, saltwater penetration, or back-flooding under closed mouth conditions. The shape of the river varies greatly from the convergence with the Soetendalsvlei wetland downstream to the Estuary mouth at the De Mond nature reserve. The system is characterized by a numerous number of river bends. The Heuningnes river is narrow in the upper portion, wider and flatter in its lower portion (C – D). Zone B (upper portion of the river) as representedin figure 1 mainly consists of mud and fine sand mixture. The upper portion of the river is also characterized by the invasion of the reeds and sedges (*Phragmites australis* and *Schoenoplectus* *scirpoides)*. While zone C (middle portion) comprise of muddy reach. with considerable mud deposits covering the channel floor and banks. The river's middle to lower portions is invaded by salt marshes (*Limonium. Salicornia and Sarcocornia* species). The Lower portion or estuary (zone D) is covered by marine sediments (Clarke et al., 2018). The estuary is reported to be invaded by expanses of seagrass known as *Zostera capensis* (Anchor Environmental Consultants. 2018).

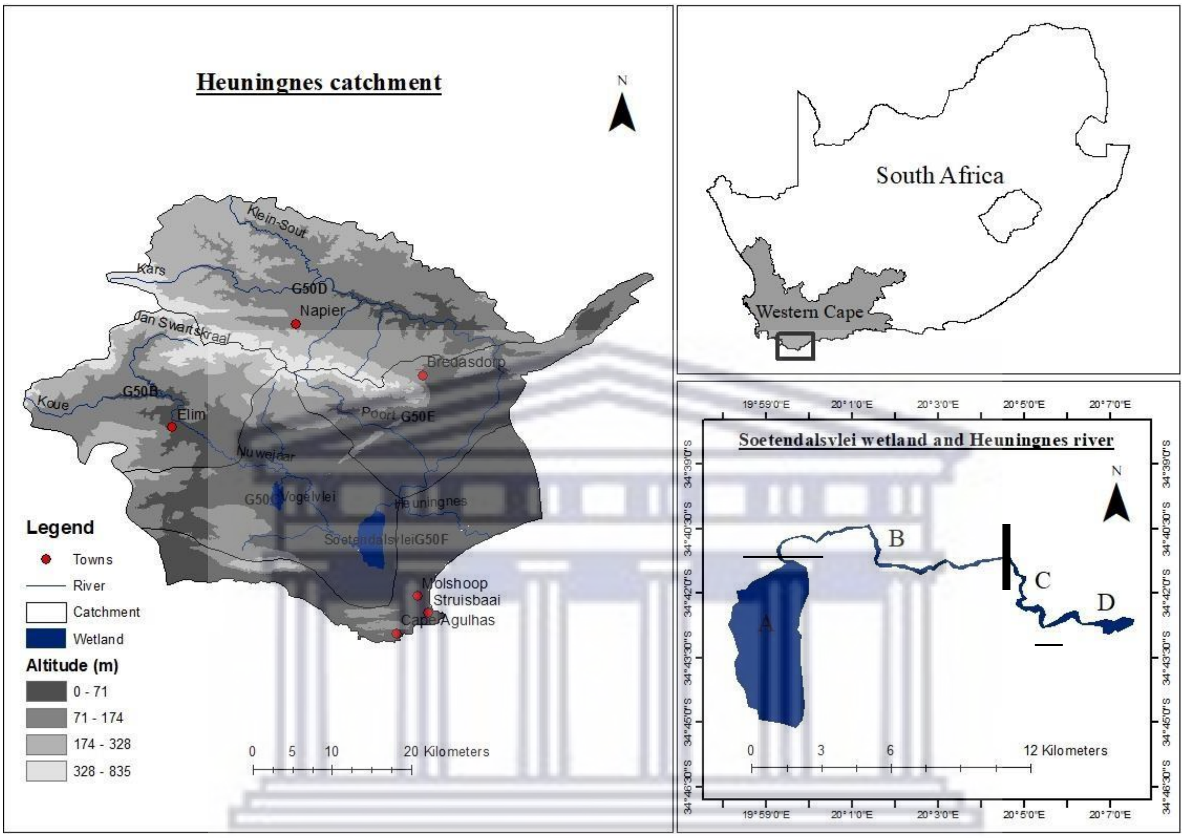

Figure 7. Location and segmentation of the study area.

The Soetendalsvlei wetland and Heuningnes river are one of the major water bodies in the Heuningnes catchment hence they were selected as study areas for investigation of morphology dynamics and area changes. Also, the wetland has been reported to be invaded by vegetation on its banks and inside the channel. On the other hand, Parry et al (2007) anticipated coastal wetlands to keep declining. While Zedler and Kerher (2005) argue that about 50 percent of wetland ecosystems have already been lost and degraded due to land use and land cover changes, mainly by conversion of wetlands to agricultural lands. Whereas agricultural areas constitute most of the Heuninges catchment's spatial extent (Anchor Environmental Consultants, 2018). Furthermore, City of Cape Town survived the 2018 drought, but the likelihood of a similar drought occurring again in future is considerable (Burls et al., 2019;

Enqvist and Ziervogel, 2019). Hence drought preparation strategies are required, and for drought preparation strategies to be established studies like morpho-dynamics studies are critical to assist with valuable information that can help planners to make better decisions choices beforehand. On the other hand, the Heuningnes river shows signs of bend erosion. This is supported by Ende (2015) noting that at a certain point of the river there is a submerged cement wall that prevents further erosion and that safeguards a cottage next to it. Also, the Heuningnes river has its river flows controlled by weirs, bridges, and is artificially breached at the mouth of the Estuary (Anchor Environmental Consultants. 2018). The control of river flows; invasion of alien vegetation at the estuary (Clark et al., 2015); and agricultural activities in this system all have impact on morphology dynamics because of their influences to geomorphic processes i.e., sediment erosion, transport, and deposition. These controls and theland use and land cover (LULC) changes make the surface water resources to be vulnerable to changes in their forms by inducing changes through erosion and deposition of sediments in geomorphic units found in these water resources. Therefore, evaluation of the extent and rate of channel morphology changes is a necessity. The mouth of the Heuningnes river has been open since the year 1940 and no back-flooding to the coastal lakes or wetlands and to nearby communities has occurred (Lubke and Hertling, 2001). The river mouth was opened to protectvaluable agricultural lands and nearby riparian communities from inundation and flooding (Bickerton, 1984; Lubke and Hertling., 2001). However, Adams and hand van Niekerk (2020)recommended that the river mouth should be permitted to close for high natural water levels to scour accumulated sediments. The evaluation of this system's channel morphology changes helps relevant and governing bodies figure out how the control of river flows; invasion of alien vegetation that is *Acacia cyclops* and *Acacia saligna* at points of the estuary (HiLand Associates, 2009) and *Acacia Longifolia* at riparian zones (Kinoti, 2018) affect this system. Notably, there is no study that sufficiently addresses the issue of morphological changes on this system. It remains unclear why spatiotemporal channel morpho-dynamics of this system are not monitored if the is a need for it to be conserved, protected, and managed as stated in the research papers by HilLand Associates (2009), Kraaij et al (2009) and Clarke et al (2018).

3.2.2 Remote sensing data set acquisition

Landsat TM image for year 1990 and three Landsat OLI images for 2015, 2017, and 2020 were downloaded from USGS Earth Explorer database. The Landsat OLI image was captured on February 27, 1990, and the other three Landsat OLI on March 20, 2015, January 4, 2017, and April 2, 2020. These images were collected from level1 which means that they are already geometrically corrected (Young et al., 2017). The images were all for the first 3 to 4 months (i.e., summer: from January to April). The reason behind the selection of images for summer season was to make sure that the water surfaces polygons for these areas are extracted at their average water levels, because it is believed that rainfall does not occur much in this region in summer. These images were all initially projected at Universal Transverse Mercator (UTM) ZONE 34 North, using the Word Geodetic System (WGS) 84 datum.

3.3 Image pre-processing

Figure 2 demonstrates a procedure and methods that were utilized to extract water bodies for change detection analysis. All the images were individually imported into ArcGIS version 10.3 for radiometric correction. The radiometric correction was a two-step procedure. The two-step procedure included the conversion to radiance (i.e., digital numbers (DN) converted to at-sensor radiance) and conversion of at-sensor radiance to top of atmosphere (TOA) reflectance. The radiometric correction was done by using the rescaling factors. These rescaling factors (or calibration coefficients) were found in metadata files. Each image is downloaded from the USGS database with its own metadata file. Different formulas were applied using the raster calculator in ArcGIS and different rescaling factors from each image metadata file were inserted to get radiation and reflectance for the images. After, the radiometric corrected images were then individually imported to QGIS version 2.18 for atmospheric correction. Dos (Dark Object Subtraction) correction was employed for atmospheric correction. Images were then georeferenced using the image-to-image method. The selected ground control points were on road intersections and the bridges that cross the river especially those in its upper portion. The ground control points were distributed over the images that were being georeferenced. The root mean square error was constantly checked. The accuracy of image georeferencing relies on the quantity and location of ground control points (Baboo and Devi., 2011). All the images georeferenced resulted to root mean square that of less than 0.5 of a pixel. The root mean square error obtained for all the images georeferenced proven that the image alignments were good for change detection analysis. The images were clipped to the study area extent to reduce processing and computation time, as well as to have a specific focus area.

3.4 Water feature extraction

Figure 8 shows methods and procedures that were followed for extractions of the wetland and the river. For the Wetland the Modified Normalized Difference Water Index (MNDWI) (Xu, 2006) was applied for enhancement and to outline the wetland water surface feature. After the classification using the MNDWI, the images were converted from raster to polygon. Water polygons for the Wetland were then extracted. The MNDWI algorithm was utilized in this study because it is one of the widely used surface water extraction techniques for identifying the land-water interface and has been shown to be a reliable water extraction index (Rokni et al., 2014; Sunder et al., 2017). Xu (2006) claimed that the MNDWI can effectively reduce or even eliminate built-up land noise, vegetation noise, and soil noise at the same time enhancing surface water areas. This is due to Xu (2006) discovery that in SWIR band water features have a spectral signature where they are characterised by low reflectance and high absorption, while built-up features and soils have high reflectance in SWIR. The MNDWI uses the green and the SWIR as shown in table 6 for water surface detection and outline. Green represents the green band, and the SWIR represents the shortwave infrared. The green band which is effective in distinguishing vegetations from other land cover classes. It is also sensitive to changes in water turbidity, sediment, and pollution plumes. Whereas the SWIR is sensitive for vegetation and soil moisture measurements. Additionally, Roy et al (2014) claimed that the SWIR is also helpful in mapping water quality in wetlands, rivers, and coastal wetlands.

Since the Heuningnes river and estuary are relatively small, the utilization of MNDWI alone would have been inappropriate because MNDWI could not detect the entire river (upper part: B could not be detected). Only the middle to lower part of the river could be detected by the MNDWI. Hence the on-screen manual digitization was employed to outline and extract the entire river, this was done with the help of spectral band combination to highlight water surface area for further processing for all different year images. The GIS manual digitization tools were employed in ArcGIS version 10.2. The on-screen manual digitization utilizes the GIS tools i.e., polyline features of ArcGIS to digitize both the left and right banks of the river channel. Polylines were then converted to polygons shapefiles for all different date images, which were created projected under the same projection WGS_1984 UTM zone 34N. Special attention was paid to assure that the river's on-screen digitalization was consistent and reliable. The images were digitized at a zooming scale of 1: 30 000 for integrity. Several studies have used this approach e.g., (Wang et al., 2011; Langat et al., 2019; Matin and Hasan, 2021; Hasan et al., 2022). Since scientists can use their judgment and understanding to determine where the border (or interface) between land and water is located, manual digitization technique for bank-line outline may have advantages over automatic delineation or computer-aided techniques. Nevertheless, the on-screen manual digitization approach is tedious, time-consuming, and somewhat inefficient when a large number of Landsat images need to be digitized. Manual digitization has been shown to be the most accurate technique.

Table 6. MNDWI equation for Landsat TM and OLI.

MNDWI index	Landsat sensor	Equation
$= \frac{Green - SWIR}{Green + SWIR}$	Landsat TM	MNDWI = (band2 – band5) / (band2 + band5)
	Landsat OLI	MNDWI = (band3 – band6) / (band3 + band6)

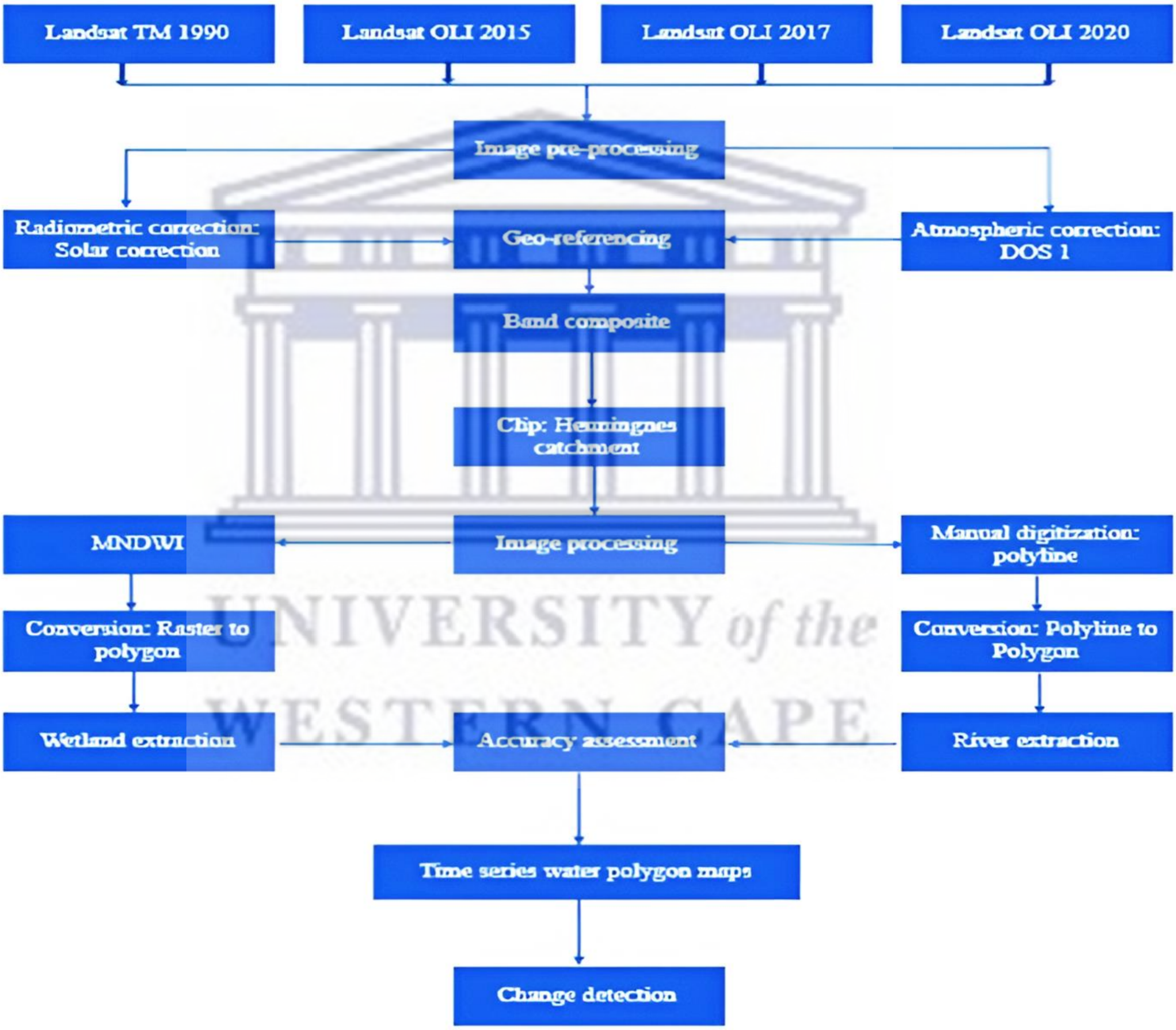

Figure 8. water polygons extraction workflow.

3.5 Results

3.5.1 Morphology changes of the wetland and river

Results in figures 9 and 11 reveal morphology changes of the wetland, whereas Table 7 highlights the area covered by the wetland from 1990 to 2020. The 1990 and 2020 maps showed the greatest changes relatively compared to other maps. The changes observed occurred in shape and sizes of wetland water polygons. In 1990, the wetland was almost unseparated, the distance or gap between the two water body sections (i.e., Soetendalsvlei north and south) was the smallest compared to years. However, the gap between the Soetendalsvlei south and Soetendalsvlei north increased over the study period. All the maps showed similar changes, where the Soetendalsvlei south was always decreasing showing the significant changes in its shape and size during the study period. The Soetendalsvlei north had no significant channel morphology changes, as compared to Soetendalsvlei south for all the years studied. Nevertheless, the 2020 polygon demonstrated the presence of vegetation inside the Soetendalsvlei north section, as well as open spaces. Those open spaces signify patch of reeds. The surface water areas got smaller and smaller as the study period moved from 1990 to year 2020. In the Soetendalsvlei south smallest changes are observed on its eastern bank and great shifts on its western bank, this implies that the eastern bank is expanding inwards the channel at a slower rate than its western side. The Soetendalsvlei wetland shape has been shown to remain almost unchanged on its north water body section.

Figures 10 and 12 demonstrate that the biggest river morphology dynamics occurred in its middle to lower (C – D) portions for the study period. In time intervals 1990-2015 and 2017-2020 river channel shifts can be seen in fewer parts of the rivers than in other two-time intervals i.e., 2015-2017 and 1990-2020. Overall, as shown in table 8 there were no huge differences in channel sizes and shapes of the river for all the different year water polygons. That is its channel size remained almost the same for all these years. Insignificant changes of the river are observed in its upper portion (B).

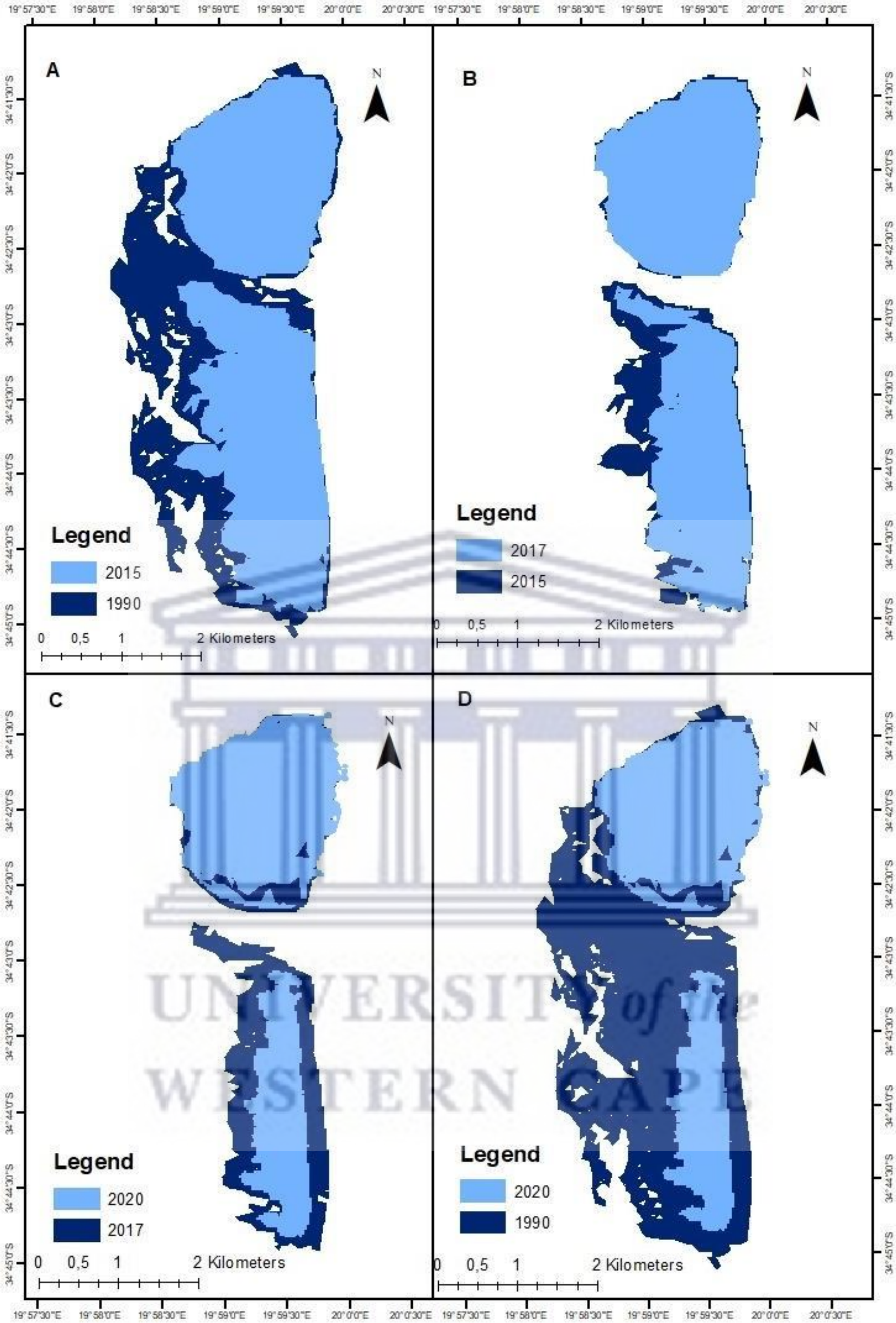

Figure 9. wetland morphology changes for time intervals: 199-2015, 2015-2017, 2017-2020, and 1990-2020.

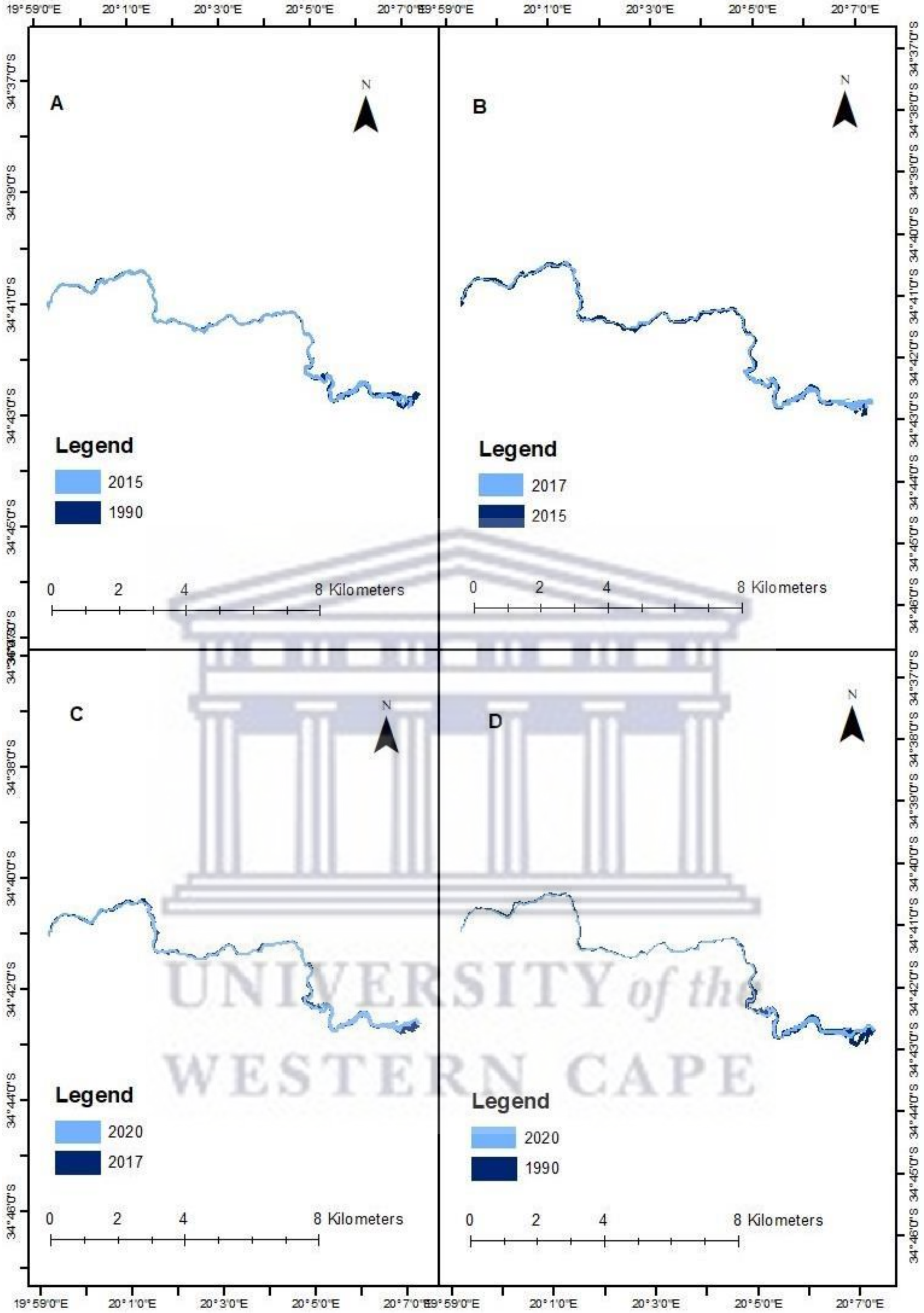

Figure 10. river morphology changes for time intervals: 1990-2015, 2015-2017, 2017-2020, and 1990-2020.

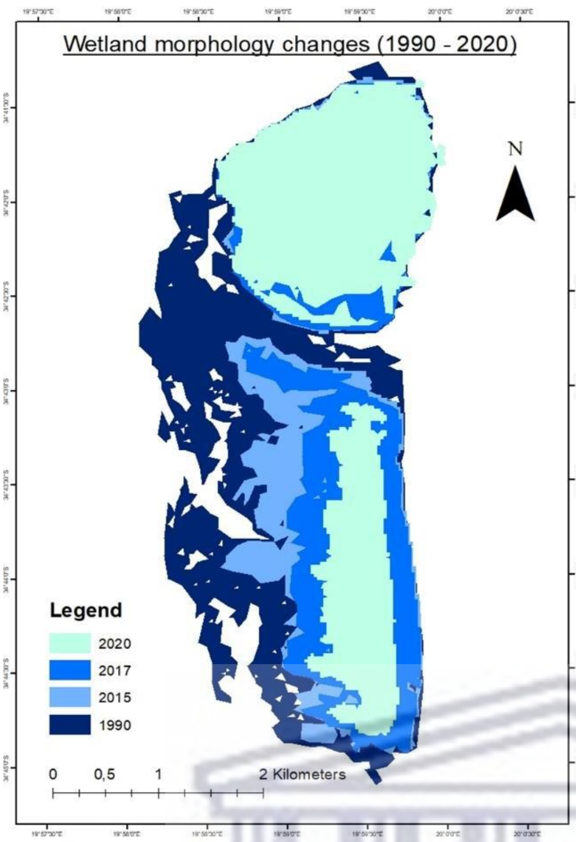

Figure 11. combined wetland morphology changes for all the years.

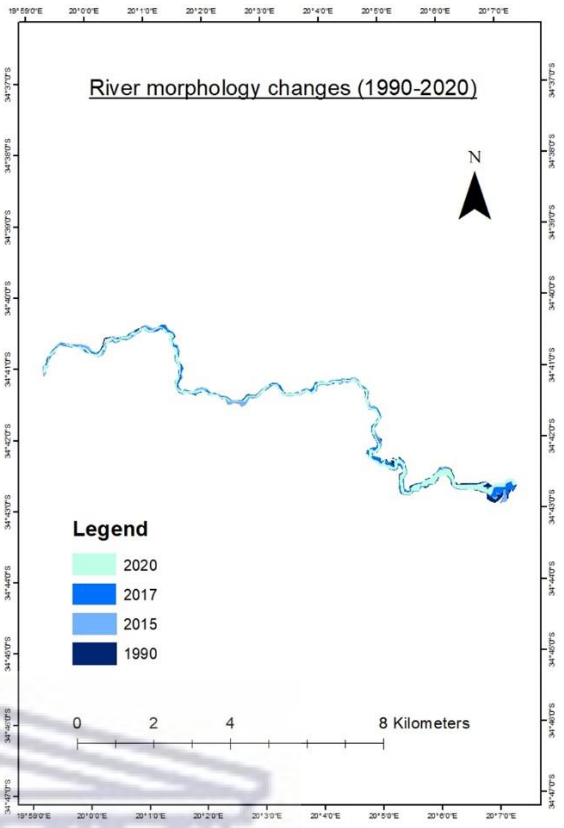

Figure 12. combined river morphology changes for all the years.

Table 7 presents the statistical results associated with the changes in wetland area between 1990 and 2020. According to statistical results provided in table 2 the surface water area covered 12.85 km^2, 8.79 km^2, 7.45 km^2, and 5.32 km^2 for the years 1990, 2015, 2017, and 2020 respectively. The results above show a continuous decreasing trend of the water surface area for the study period. The wetland surface water area decreased by 4.06 km^2 between 1990 and 2015, which is relatively the highest decrease observed in the table as compared to other time intervals. The decrease between 2015 and 2017 was 1.34 km^2, and the decrease from year 2017 to 2020 was 2.14 km^2. The overall water surface area reduction from 1990 to 2020 is –7.53 km^2. The minimum decrease being -1.34 km^2 between 2015 and 2017. The wetland always got narrower and narrower from 1990 to 2020. Even though, significant changes are observed in the Soetendalsvlei south, especially on its western side. Overall accuracy for wetland classification was 98.18 %, 94.55 %, 92.73 %, and 92.73 % for 1990, 2015, 2017, and 2020 respectively.

Table 7. Soetendalsvlei wetland area changes.

Year	Surface water area (km²)	Surface water area change (km²)			Total surface water area changes (km²)
		(1990 – 2015)	(2015 – 2017)	(2017 – 2020)	(1990 – 2020)
1990	12.85				
2015	8.79	-4.06			
2017	7.45		-1.34		
2020	5.32			-2.14	-7.53

The statistical results in Table 8 show changes of the river surface water area for the entire period of the study. According to these results the surface water area covered 1.56 km^2, 1.52 km^2, 1.55 km^2, and 1.31 km^2 for the years 1990, 2015, 2017, and 2020 respectively. These results show a fluctuating area trend (constant increase and decrease). The overall surface water area changes from 1990 to 2020 summed up to -0.26 km^2 that is, the area decreased by 0.26 for the whole study period. Relatively the greatest decrease was between the year 2017 and 2020 and it was -0.24 km^2. The smallest surface water area decrease was observed between the year 1990 and 2015, the decrease was -0.04 km^2. In summary significant Heuningnes river morphology changes are observed in its middle and lower. Especially, the estuary (or part D) has been constantly changes its shape and its position.

Table 8. Heuningnes river area changes.

Year	Surface water area (km²)	Surface water area change (km²)			Total surface water area change (km²)
		(1990 – 2015)	(2015 – 2017)	(2017 – 2020)	(1990 – 2020)
1990	1.56				
2015	1.52	-0.04			
2017	1.55		0.02		
2020	1.31			-0.24	-0.26

3.5.2 Accuracy assessment of remote sensing image classification

Table 9 shows the classification accuracies associated with the classification of Landsat from 1990 to 2020 for wetland. Overall accuracies for wetland classification were 98.18 %, 94.55 %, 92.73 %, and 92.73 % for all the years from 1990 to 2020. The lowest overall accuracy was 92.73 % which was obtained for 2017 and 2020. The highest overall accuracy was 98.18 %, it was obtained for the polygon produced from 1990 image, it had no misclassifications for water surface which made it to have a commission error of 0.00 % and user’s accuracy being 100 %. The 1990 polygon with highest overall accuracy had 3.23 % omission error (that is the number of river water surfaces that were left out from the classified image), resulting to it to have producer’s accuracy of 96.77 %.

Table 9. accuracy assessment table for wetland.

1990	**Water bodies**	**Non-water bodies**	**Total**	**Commission error**	**User's accuracy**
Water bodies	30	0	30	0.00%	100.00%
Non-water bodies	1	24	25	4.00%	96.00%
Total	31	24	55		
Omission error	3.23%	0.00%			
Producer's accuracy	96.77%	100.00%			
Overall accuracy	98.18%				
Kappa coefficient	0.96				
2015	**Water bodies**	**Non-water bodies**	**Total**	**Commission error**	**User's accuracy**
Water bodies	28	2	30	6.67%	93.33%
Non-water bodies	1	24	25	4.00%	96.00%
Total	29	26	55		
Omission error	3.45%	7.69%			
Producer's accuracy	96.55%	92.31%			
Overall accuracy	94.55%				
Kappa coefficient	0.89				

2017	**Water bodies**	**Non-water bodies**	**Total**	**Commission error**	**User's accuracy**
Water bodies	30	0	30	0.00%	100.00%
Non-water bodies	4	21	25	16.00%	84.00%
Total	34	21	55		
Omission error	11.76%	0.00%			
Producer's accuracy	88.24%	100.00%			
Overall accuracy	92.73%				
Kappa coefficient	0.85				
2020	**Water bodies**	**Non-water bodies**	**Total**	**Commission error**	**User's accuracy**
Water bodies	29	1	30	3.33%	96.67%
Non-water bodies	3	22	25	12.00%	88.00%
Total	32	23	55		
Omission error	9.38%	4.35%			
Producer's accuracy	90.63%	95.65%			
Overall accuracy	92.73%				
Kappa coefficient	0.85				

Table 10 shows accuracy metrices of image classification for river morphology from 1990 to 2020. The overall accuracies for river classification were 87.06 %, 77.65 %, 81.18 %, 78.82 % for 1990, 2015, 2017, and 2020 respectively. The lowest overall accuracy for the river classification was 77.65 % which was obtained from the 2015 image, with user's accuracy of 65.45 % and producer's accuracy of 100 % (meaning that there was no river water surface was left out from the classified polygon). Highest overall accuracy for river polygon was obtained for 1990 image being 87.06 %, with user's and producer's accuracies being 85.45 % and 94.00 % respectively.

Table 10. Accuracy assessment table for river.

1990	**Water bodies**	**Non-water bodies**	**Total**	**Commission error**	**User's accuracy**
Water bodies	47	8	55	14.55%	85.45%
Non-water bodies	3	27	30	10.00%	90.00%
Total	50	35	85		
Omission error	6.00%	22.86%			
Producer's accuracy	94.00%	77.14%			
Overall accuracy	87.06%				
Kappa coefficient	0.73				
2015	**Water bodies**	**Non-water bodies**	**Total**	**Commission error**	**User's accuracy**
Water bodies	36	19	55	34.55%	65.45%
Non-water bodies	0	30	30	0.00%	100.00%
Total	36	49	85		
Omission error	0.00%	38.78%			
Producer's accuracy	100.00%	61.22%			
Overall accuracy	77.65%				
Kappa coefficient	0.57				
2017	**Water bodies**	**Non-water bodies**	**Total**	**Commission error**	**User's accuracy**
Water bodies	42	13	55	23.64%	76.36%
Non-water bodies	3	27	30	10.00%	90.00%
Total	45	40	85		
Omission error	6.67%	32.50%			
Producer's accuracy	93.33%	67.50%			
Overall accuracy	81.18%				
Kappa coefficient	0.62				
2020	**Water bodies**	**Non-water bodies**	**Total**	**Commission error**	**User's accuracy %**
Water bodies	37	18	55	32.73%	67.27%

Non-water bodies	0	30	30	0.00%	100.00%
Total	37	48	85		
Omission error	0.00%	37.50%			
Producer's accuracy	100.00%	62.50%			
Overall accuracy	78.82%				
Kappa coefficient	0.59				

3.6 Discussion

The objective of this chapter was to expand knowledge about the spatiotemporal channel morphology adjustments that occurred in Soetendalsvlei wetland and Heuningnes river since year 1990 until 2020 using remote sensing and water-based index. Wetland water features (polygons) were extracted using spectral indexing through MNDWI, while river water features were extracted using on-screen manual digitization. The human activities such as LULC changes, water abstraction, flow modifications and others have led surface water resources to being dynamic environmental systems. The Soetendalsvlei wetland and Heuningnes river are no exception, and their morphological dynamics are influenced by a range of factors including tides, sea level fluctuations, controlled flows, and vegetation growth inside channel or on banks. These factors have altered its natural morphological dynamics.

According to the results of this study as shown in table 7 the water surface area of the wetland covered 12.85 km^2, 8.79 km^2, 7.45 km^2, and 5.32 km^2 for the years 1990, 2015,2017, and 2020 respectively. Noble and Hemens (1978) anticipated that the Soetendalsvlei wetland covered an area of 20 km^2. This shows that the wetland is continually decreasing in its size, and this is occurring at a fast rate. If the decreasing trend continues like this, that means the wetland will be lost in the near future, especially its southern section. The decline in size of the Soetendalsvlei wetland overtime supports predictions by Parry et al (2007) that coastal wetland will keep declining because of human, climate, and sea level rise effects.

The results from this study showed that the gap between these water body sections increases continuously. Liira et al (2010) and Canavan et al (2018) claim that changes in hydrology, enhanced sedimentation, and enrichment of nutrients from escalated agricultural activities are the most likely factors to contribute to growth of reeds inside and on banks of the Soetendalsvlei wetland. This possibly implies that reed stands are expanding in this area and that they may need to be eradicated or best be minimized because they also provide habitats for animal species and help in well-functioning of the wetland to control high flows e.g., from flooding. Anchor Environmental Consultants (2018) claim that reed stands separate the Soetendalsvlei north and south sections. Soetendalsvlei south section's western bank grows inward the channel. This also due to growth of reed stands expanding fast on the western side. This is supported by Gordon (2012) claiming that strong westerly winds in this area facilitate the growth of vegetation in the western banks of the wetland. These reed stands can also be observed growing inside the channel, as a result small open spaces were observed during accuracy assessment. These very small patches (coverage by vegetation) made accurate classification of water surface area for wetland to decrease slightly because these in most of the times were could not be detected by MNDWI, and they were only seen during accuracy assessment.

Heuningnes river shows no significant changes in its shape in the upper section (B). Significant shape changes are observable in the middle to lower sections of the river. River water surface area changes showed a fluctuating trend. This trend can be caused by several factors such as rainfall variability, climate changes, human activities because a river is shaped by a variety of forces and factors. River channel is shaped through interactions between flows, sediment movement, and vegetation (Corenblit et al., 2009; Paola, 2011; Gurnell et al., 2012; Bertagni et al., 2018), and Heuningnes river is no exception. Gurnell (2014) labelled vegetation as river system engineers. Gurnell (2014) also further articulated that the above ground biomass of vegetation influences the flow and sediment regimes, whereas the below ground biomass of vegetations has a huge impact on the river channel stability (i.e., its susceptibility to soil erosion). Ende (2015) claim that upper section (B) of the Heuningnes river is bound by vegetation on its banks and the vegetations becomes sparse going down the river and river gets wider, until to the estuary where sandbanks are observable, and river becomes unconfined. This implies that vegetation keeps the Heuningnes river channel confined and stable because there are no significant channel changes observed in upper section (B) with intense vegetation on its banks. An estuary is found where a river meets the sea. Ende (2015) also claims that Heuningnes river on its lower section (D) is not well defined. On the other hand, Bickernton (1984) claims the Heuningnes estuary to be very active depending on hydrodynamics and that its location and depth changes with time. According to the results of this study, what Bickerton (1984) and Ende(2015) claim is also true. As shown in the map the river polygons for all the years have different shapes, sizes, and location of the river mouth (D) or estuary. This implies that the estuary sandbanks are significantly impacted by tidal effects and sea level fluctuations influencing the river hydrodynamics, which then makes the river estuary to constantly shift and to change in its shape. The staircase edge effect made it a bit challenging to manually digitize (on screen) the river. However, due care was taken while the river polygons were extracted.

Results of area changes for wetland and the river do not show the same trend. The results for the wetland showed a decreasing trend while river results showed a fluctuating trend. This proves the claims by Clarke et al (2018), that the wetland and river are not connected. Or this can be due to tidal effects and sea level fluctuations, as their impacts would not be the same for river and wetland dependable on their distance from the shore. Factors and forces affecting the Heuningnes river include sediment supplies form agricultural lands via wind currents and river flows, to hydrodynamics which are mainly influenced by rainfall variability, flows being controlled and tidal effects since the river mouth is open (Ende, 2015; Anchor Environmental Consultants, 2018).

3.7 Conclusion

The objective of this chapter was to assess morphological dynamics of the Heuningnes river and Soetendalsvlei wetland from 1990 to 2020. This study was executed by processing Landsat images for analysis and interpretation through use of GIS techniques. Spectral indexing (i.e., use of MNDWI) for extraction of wetland water surface area. Manual digitization method was only utilized to detect and extract river water feature (or polygon). The study revealed that the greatest water area changes occurred between 1990 and 2015 for the wetland. Which revealed that the water surface area of the wetland decreased by -4.06 km^2. While the greatest area change for the river was observed between 2017 and 2020 showing a decrease by -0.24 km^2. Significant changes in channel form were observed in the Soetendalsvlei south where reed stands were observed constricting this water body section dramatically. River showed significant channel form changes on its middle, and lower portion (estuary) constantly shifting changing its position and shape. It is fair enough to predict that the wetland will be lost if the decreasing trend follows continuously, especially the Soetendalsvlei south section. The Soetendalsvlei wetland is predominantly affected by the reed stands i.e., vegetation growth. It is also appropriate to conclude that the river is mostly influenced by agricultural areas since agricultural areas are the main landcovers surrounding the river. Nevertheless, these agricultural areas are not critically influencing it because the fluctuation trend was observed for the river area changes.

3.8 Recommendations

Based on the findings, several recommendations have been proposed for future studies in the field:

- To ensure consistency in the analysis, it is crucial to consider using images captured during periods when water levels are similar. This is important because variations in water levels can significantly affect the appearance and shape of water bodies, potentially impacting the reliability of the analysis.
- For effective extraction of surface water bodies, it is recommended to focus on larger water bodies that can be easily detected and delineated with high accuracy. This ensures that water features or water body polygons can be extracted without significant difficulties.
- When studying small water bodies such as rivers and streams, it is advisable to utilize finer resolution images. Finer image resolution provides greater information and clarity, enhancing precision in the analysis. Researchers analysing small rivers or streams should prioritize the use of finer resolution images for their research.
- To improve the reliability of the study, it is advised to incorporate as many images as possible. Increasing the number of images used in the analysis can enhance the accuracy and robustness of the findings.

By implementing these recommendations, future studies can enhance the quality and reliability of their analyses regarding surface water bodies.

References

Adams, J. B., & Van Niekerk, L. (2020). Ten principles to determine environmental flow requirements for temporarily closed estuaries. *Water*, *12*(7), 1944.

Alcántara-Ayala, I. (2002). Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries. *Geomorphology*, *47*(2-4), 107-124.

Anchor Environmental Consultants. (2018). Determination of the Ecological Reserve for the Heuningnes Estuary. *Report prepared for the Breede-Gouritz Catchment Management Agency*. 206 p

Baboo, S. S., & Devi, M. R. (2011). Geometric correction in recent high resolution satellite imagery: a case study in Coimbatore, Tamil Nadu. *International Journal of Computer Applications*, *14*(1), 32-37.

Bertagni, M. B., Perona, P., & Camporeale, C. (2018). Parametric transitions between bare and vegetated states in water-driven patterns. *Proceedings of the National Academy of Sciences*, *115*(32), 8125-8130.

Bertrand, M., Piégay, H., Pont, D., Liébault, F., & Sauquet, E. (2013). Sensitivity analysis of environmental changes associated with riverscape evolutions following sediment reintroduction: geomatic approach on the Drôme River network, France. *International journal of river basin management*, *11*(1), 19-32.

Bickerton, I. B. (1984). *Heuningnes (CSW19)*. CSIR, National Research Institute for Oceanology.

Boothroyd, R. J., Nones, M., & Guerrero, M. (2021). Deriving planform morphology and vegetation coverage from remote sensing to support river management applications. *Frontiers in Environmental Science*, *9*, 146.

Burls, N. J., Blamey, R. C., Cash, B. A., Swenson, E. T., Fahad, A. A., Bopape, M. J. M., ... & Reason, C. J. (2019). The Cape Town "Day Zero" drought and Hadley cell expansion. *Npj Climate and Atmospheric Science*, *2*(1), 1-8.

Canavan, K., Paterson, I. D., Lambertini, C., & Hill, M. P. (2018). Expansive reed populations—alien invasion or disturbed wetlands?. *AoB Plants*, *10*(2), ply014.

Carolissen, M. (2021). Spatial and temporal variations of inundation and their influence on ecosystem services from a shallow coastal lake. A case study of Soetendalsvlei in the Nuwejaars catchment, South Africa.

Clark, B. M., van Niekerk, L., Turpie, J., Taljaard, S., Adams, J., Cowie, M., A, B., & Lamberth, S. (2015). *Determination of the Ecological Water Requirements for the KleinEstuary*. *September*, 199. https://doi.org/10.13140/RG.2.2.28830.46401

Corenblit, D., Steiger, J., Gurnell, A. M., & Naiman, R. J. (2009). Plants intertwine fluvial landform dynamics with ecological succession and natural selection: a niche construction perspective for riparian systems. *Global Ecology and Biogeography*, *18*(4), 507-520.

Dallas, H., Seymour, C. L., Snaddon, K., & Ewart-Smith, J. (2006). Identification and collation of existing information on the wetlands of the Western Cape. *Table Mountain Fund of WWF-SA, Report compiled by Freshwater Consulting Group, Cape Town*.

Ende, G. J. (2015). *Salinity and relative sea level rise in Heuningnes River South Africa: A field based Delft3D study* (Master's thesis, University of Twente).

Enqvist, J. P., & Ziervogel, G. (2019). Water governance and justice in Cape Town: An overview. *Wiley Interdisciplinary Reviews: Water*, *6*(4), e1354.

Fortune, F. (2018). The impact of climate change and climate variability on coastal wetland ecosystem dynamics.

Gordon, N. (2012). *The past and present Limnology of the Soetendalsvlei wetlands, Agulhas coast, South Africa* (Doctoral dissertation, Nelson Mandela Metropolitan University).

Grabowski, R. C., Surian, N., & Gurnell, A. M. (2014). Characterizing geomorphological change to support sustainable river restoration and management. *Wiley Interdisciplinary Reviews: Water*, *1*(5), 483-512.

Guo, M., Li, J., Sheng, C., Xu, J., & Wu, L. (2017). A review of wetland remote sensing. *Sensors*, *17*(4), 777.

Gurnell, A. M., Bertoldi, W., & Corenblit, D. (2012). Changing river channels: The roles of hydrological processes, plants and pioneer fluvial landforms in humid temperate, mixed load, gravel bed rivers. *Earth-Science Reviews*, *111*(1-2), 129-141.

Gurnell, A. M., Bertoldi, W., & Corenblit, D. (2012). Changing river channels: The roles of hydrological processes, plants and pioneer fluvial landforms in humid temperate, mixed load, gravel bed rivers. *Earth-Science Reviews*, *111*(1-2), 129-141.

Hasan, G. J., Jabir, A. A., & Anam, M. M. (2022). Monitoring bank-line movements of the rivers flowing across the Sundarbans using remote sensing and GIS techniques. *Regional Studies in Marine Science*, *56*, 102679.

Hayashi, M., & van der Kamp, G. (2021). Water level changes in ponds and lakes: the hydrological processes. In *Plant disturbance ecology* (pp. 321-351). Academic Press.

HiLand Associates. (2009). Draft ESTUARY MANAGEMENT for the Heuningness Estuary.

Hoekstra, T., & Waller, L. (2014). De Mond Nature Reserve Complex: Protected Area Management Plan. *Unpublished report*.

Jones, S., & Reinke, K. (Eds.). (2009). *Innovations in remote sensing and photogrammetry*. Springer Science & Business Media.

Kinoti, I. K. (2018). *Integraded hydrological modeling of surface and groundwater interactions in Heuningnes catchment (South Africa)* (Master's thesis, University of Twente).

Kraaij, T., Hanekom, N., Russell, I. A., & Randall, R. M. (2009). Agulhas National Park State of Knowledge. *Unpublished Internal Report, South African National Parks*, *51*.

Kuo, C. W., Chen, C. F., Chen, S. C., Yang, T. C., & Chen, C. W. (2017). Channel planform dynamics monitoring and channel stability assessment in two sediment-rich rivers in Taiwan. *Water*, *9*(2), 84.

Langat, P. K., Kumar, L., & Koech, R. (2019). Monitoring river channel dynamics using remote sensing and GIS techniques. *Geomorphology*, *325*, 92–102. https://doi.org/10.1016/j.geomorph.2018.10.007

Li, J., Peng, B., Wei, Y., & Ye, H. (2021). Accurate extraction of surface water in complex environment based on Google Earth Engine and Sentinel-2. *PloS one*, *16*(6), e0253209.

Li, W., Du, Z., Ling, F., Zhou, D., Wang, H., Gui, Y., ... & Zhang, X. (2013). A comparison of land surface water mapping using the normalized difference water index from TM, ETM+ and ALI. *Remote Sensing*, *5*(11), 5530-5549.

Liira, J., Feldmann, T., Mäemets, H., & Peterson, U. (2010). Two decades of macrophyte expansion on the shores of a large shallow northern temperate lake—A retrospective series of satellite images. *Aquatic Botany*, *93*(4), 207-215.

Lubke, R. A., & Hertling, U. M. (2001). The role of European marram grass in dune stabilization and succession near Cape Agulhas, South Africa. *Journal of Coastal Conservation*, *7*, 171-182.

Matin, N., & Hasan, G. J. (2021). A quantitative analysis of shoreline changes along the coast of Bangladesh using remote sensing and GIS techniques. *Catena*, *201*, 105185.

Ndlala, N. C., & Dube, T. (2022). Use of remotely sensed derived metrics to assess wetland vegetation responses to climate variability-induced drought at the Soetendalsvlei wetland system in the Heuningnes Catchment, Western Cape province, South Africa. *African Journal of Aquatic Science*, *47*(2), 185-196.

Noble, R. G., & Hemens, J. (1978). *Inland water ecosystems in South Africa–a review of research needs*. National Scientific Programmes Unit: CSIR.

Paola, C. (2011). Co-evolution of rivers and plants. *Nature Geoscience*, *4*(9), 583-584.

Parry, M. L., Canziani, O., Palutikof, J., Van der Linden, P., & Hanson, C. (Eds.). (2007). *Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC* (Vol. 4). Cambridge University Press.

Raj, C., & Singh, V. (2022). Assessment of planform changes of the Ganga River from Bhagalpur to Farakka during 1973 to 2019 using Satellite Imagery. *ISH Journal of Hydraulic Engineering*, *28*(1), 87–97. https://doi.org/10.1080/09715010.2020.1812123

Rokni, K., Ahmad, A., Selamat, A., & Hazini, S. (2014). Water feature extraction and change detection using multitemporal Landsat imagery. *Remote sensing*, *6*(5), 4173-4189.

Roy, D. P., Wulder, M. A., Loveland, T. R., Woodcock, C. E., Allen, R. G., Anderson, M. C., ... & Zhu, Z. (2014). Landsat-8: Science and product vision for terrestrial global change research. *Remote sensing of Environment*, *145*, 154-172.

Sunder, S., Ramsankaran, R. A. A. J., & Ramakrishnan, B. (2017). Inter-comparison of remote sensing sensing-based shoreline mapping techniques at different coastal stretches of India. *Environmental monitoring and assessment*, *189*(6), 1-13.

Tang, Z., Ou, W., Dai, Y., & Xin, Y. (2012). Extraction of water body based on LandSat TM5 imagery–a case study in the Yangtze River. In *International Conference on Computer and Computing Technologies in Agriculture* (pp. 416-420). Springer, Berlin, Heidelberg.

Wang, W., Yao, T., & Yang, X. (2011). Variations of glacial lakes and glaciers in the Boshula mountain range, southeast Tibet, from the 1970s to 2009. *Annals of Glaciology*, *52*(58), 9-17.

Xu, H. (2006). Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. *International journal of remote sensing*, *27*(14), 3025-3033.

Young, N. E., Anderson, R. S., Chignell, S. M., Vorster, A. G., Lawrence, R., & Evangelista, P. H. (2017). A survival guide to Landsat preprocessing. *Ecology*, *98*(4), 920-932.

Zedler, J. B., & Kercher, S. (2005). Wetland resources: status, trends, ecosystem services, and restorability. *Annu. Rev. Environ. Resour.*, *30*, 39-74.

CHAPTER 4

An assessment of river and wetland morphology dynamics using geospatial techniques

4.1 Findings

The study investigated the fluctuating area trends of waterbodies in relation to LULC changes. The results revealed that the waterbodies class exhibited varying area changes, likely due to these LULC modifications. Conversely, the changes in the bare land class had no correlation with the waterbody class area alterations. This suggests that the bare land class has no significant impact on waterbody area changes within this catchment. Regarding LULC classes, the study observed a decrease in vegetation class in the northern parts of the Heuningnes catchment, while the middle to southern areas showed consistent vegetation maintenance. Agriculture class expansion was evident on sloped terrains, low-lying flat areas, and the north-western part of the catchment. Both agriculture and vegetation were found to be the most influential LULC classes concerning changes in the waterbodies within the study area.

To investigate the impacts of LULC changes on waterbodies, the study focused on two major waterbodies in the area: Soetendalsvlei wetland and the Heuningnes River. Monitoring their area changes and morphology dynamics led to discoveries that the expansion of vegetation and agriculture near waterbodies in the catchment led to reduced water availability. This reduction was mainly attributed to water consumption effects, irrigation purposes, sediment supply effects, and their extensions, all of which compromised the shapes of the waterbodies. Specifically, Soetendalsvlei wetland experienced adverse effects due to the continuous constriction caused by the expansion of vegetation (reeds). On the other hand, vegetation was found to support the shape of the Heuningnes river, as the upper portion of the river, surrounded by dense vegetation, showed no changes in shape. However, the middle portion, with mild vegetation cover on the banks, exhibited shape changes. The lower portion (estuary) with sand banks showed significant shape changes, emphasizing the influence of vegetation absence on the sand banks, resulting in more shifts and shape changes. The study's results also revealed that the Heuningnes estuary exhibited different morphological dynamics over the years. The expansion of vegetation near water-related ecosystems is believed to be caused by an improved supply of sediments and nutrients from the agriculture class. This highlights the intricate relationships between LULC changes, vegetation expansion, and their impacts on water bodies within the Heuningnes catchment.

4.2 Conclusion

The primary objective of this study was to assess the LULC changes in the Heuningnes catchment and their impact on surface water resources. The major classes identified as influential in this catchment were the vegetation class and agriculture class. These classes were observed to expand in areas with concentrated water bodies, specifically in low-lying flat terrains of the catchment. As these classes expanded, there was a noticeable reduction in the sizes of water bodies. The expansion of vegetation, especially reeds, had a significant influence on the morphology dynamics of these water resources, particularly the wetland. The growth of vegetation within these water bodies led to a reduction in their sizes. Therefore, it can be concluded that these two LULC classes contributed to the reduction of water body sizes in this catchment. Furthermore, the expansion of the vegetation class was likely driven by the increase in Agriculture, as the rise in vegetation in water resources seemed to be linked to a higher supply of sediments and nutrients from the agriculture class.

The study's results and conclusions have practical implications for water managers and governing bodies. The findings can be used to develop effective mitigation and adaptive strategies for conserving and ensuring the sustainability of water resources in the Heuningnes catchment. By understanding the relationship between LULC changes, particularly the expansion of Vegetation and Agriculture, and their impacts on water bodies, appropriate measures can be taken to protect and manage these valuable resources. This, in turn, will contribute to the overall conservation and long-term sustainability of water resources in the Heuningnes catchment.