



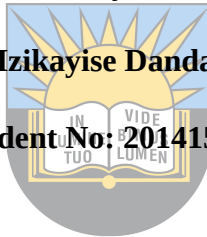
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**ASSESSING THE EXTENT AND IMPACTS OF ILLEGAL SAND MINING ALONG
THE WILD COAST ZONE OF THE AMATHOLE DISTRICT IN THE EASTERN
CAPE PROVINCE, SOUTH AFRICA**

By

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A Dissertation submitted in fulfilment of the requirements for the Degree of
University of Fort Hare
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MASTER OF SCIENCE IN GEOGRAPHY, in the

Department of Geography and Environmental Science

Faculty of Science and Agriculture of Fort Hare

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Abstract

Sand mining is widespread, and its practice is increasing in developing and developed nations. However, the increased demand for sand has led some communities to mine sand illegally. Illegal sand mining brings irreversible environmental damage, and the physical and environmental effects of sand mining have developed into crises that often result in changes in land use dynamics. The Wild Coast zone of South Africa is recognised as an international biodiversity hotspot. Therefore, assessing the extent and impacts of illegal sand mining in this biodiversity hotspot is crucial for guiding environmental planning. However, traditional methods for monitoring illegal sand mining are time-consuming and costly. This study employed a monitoring and modelling spatiotemporal approach, which is non-destructive, cost-effective, covers larger areas, and is a time-saving alternative to conventional methods. The research objectives were: (i) to evaluate the spatial and temporal trends of illegal sand mining (i.e., pit size) along the coastal zone from Kei River mouth to Lubanzi River mouth over the last 22 years (2000 – 2022) and (ii) to assess the impact of illegal sand mining activities on the landscape dynamics (i.e., land use change and vegetation cover change) in the study area. Aerial images and field surveys were used to assess the extent of illegal sand mining over the last few years. Additionally, 30-meter resolution images of Landsat from 2000 to 2022 were used to assess land cover and vegetation changes. The comprehensive analysis of illegal sand mining activities along the Eastern Cape coast from 2000 to 2022 has provided valuable insights into the escalating challenges of unauthorised extraction. The study identified a minimum of 24 illegal sand mining sites, with evidence indicating a significant growth in illegal sand mining activities over the observed period. The spatial extent of sand pits has expanded, reflecting the increasing demand for construction materials driven by rapid population growth. The physical damage caused by illegal sand mining was observed across most areas, with noticeable aftereffects such as the creation of sand pits and dumping. These findings underscore the urgency of addressing the drivers behind the growth of illegal sand mining, particularly the need for stronger legislation and law enforcement to curb unauthorised extraction. The assessment of the impact of illegal sand mining on landscape dynamics revealed significant changes in land use patterns, particularly in the conversion of vegetated lands to bare soil. The transition from other vegetation to bare soil highlights the early stages of environmental degradation resulting from sand mining activities. Additionally, the decline in forest and water areas underscores the loss of critical ecosystems along the coastal zone. This study highlights the pressing need for comprehensive regulatory measures and stakeholder collaboration to address the growing threat of illegal sand mining. By understanding sand

mining activities' spatial and temporal trends and their impact on landscape dynamics, policymakers can develop targeted interventions to safeguard coastal ecosystems and promote sustainable development in the Eastern Cape region and beyond.

Keywords: Illegal sand mining, legislation, Wild Coast, Geospatial Analysis.



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Declaration

This statement confirms that, unless otherwise noted by citation of public sources, the research contained in this dissertation is entirely my effort and has not been submitted to any other institution except for the University of Fort Hare, which is the institution that awards degrees. Therefore, this dissertation has not been submitted for any degree, certificate, or examination at any other college or university.

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Date June 2024

A handwritten signature in black ink, appearing to read 'Mzikayise Dandala', written over a horizontal line.

Signature:

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Dedication

I dedicate this dissertation to my late parents, Hilda Ntombiziyanda Dandala and Douglas Manqina Dandala. I also dedicate it to my twin daughters, brothers, and sisters.



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Acknowledgement

First and foremost, I would like to thank my ancestors for making it possible for me to complete this dissertation, without Indlozi lasekhaya, I personally don't think I will make it.

Special acknowledgements to the following:

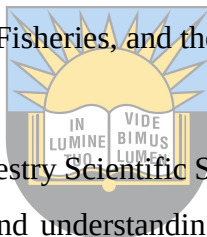
Prof. W Nel, special thanks to you for the supervision, direction, motivation, guidance, and leadership.

Prof. A.M Kalumba, thanks for the support, constructive comments, motivation, and supervision.

Special thanks to the staff and colleagues in the Department of Geography. Their constructive inputs from the concept, proposal, defense and beyond that. Your support, advice, and direction that the reason I managed to finish my dissertation.

Funding, the Department of Forestry, Fisheries, and the Environment (DFFE) for funding this research.

Colleagues: Thanks to the team of Forestry Scientific Services, my supervisor Mr Jakavula for the support their acknowledgement and understanding, in cases where there was a need to balance work and the research. Also, would like to thank Afuye, Afika and Lwandile for their assistance from day one day until, the last of the dissertation.



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Table of Contents

Abstract	i
Declaration.....	iii
Dedication	iv
Acknowledgement	v
List of figures.....	ix
List of tables.....	xi
List of Acronyms	xii
Chapter 1: Background and overview of the study.....	1
1.1 Introduction	1
1.2 Problem statement.....	2
1.3 Research aim	3
1.4 Research objectives	3
1.5 Conceptual analytical framework.....	3
1.6 Significance of the study	4
1.7 Dissertation layout.....	5
Chapter 2: Literature review	7
2.1 Introduction	7
2.2 Positive and negative impacts of global sand mining and its associated activities.....	8
2.3 Legislations pertaining to sand mining in South Africa.....	9
2.4 Reporting on illegal sand mining along the Wild Coast	10
2.5 Coastal sand mining in South Africa: An overview.....	11
2.6 Coastal vulnerability due to sand mining.....	12
2.7 Remote Sensing and Geographical Information Systems in monitoring illegal sand mining.....	17
Chapter 3: Study area and research design	18
3.1 Introduction	18
3.2 Study area.....	18
3.3 Coastline vegetation	19
3.4 Geology	21
3.5 Research design.....	22
3.5.1 Data collection for objective 1.....	23
3.5.2 Data collection for objective 2.....	23
3.5.3 Flowchart adopted for the research design	24

3.6 Ethical Consideration	24
Chapter 4: Assessment of spatiotemporal trends of illegal sand mining (i.e., pit size) along the coastal zone from Kei River mouth and Lubanzi River mouth.	26
4.1. Introduction	26
4.2 Methods and materials	27
4.2.1 Data Processing	28
4.2.2 Creation of Illegal Sand Mining Maps	29
4.2.3 Error and Accuracy Assessment of Digitised Illegal Sand Mining Sites	29
4.2.4 Change detection analysis	30
4.3 Results and Discussions	30
4.3.1 Field Data Collection.....	33
4.3.2 Illegal mining sites 2000, 2010, and 2022.....	33
4.3.3 Change detection analysis	42
4.4 Factors contributing to illegal sand mining.....	44
4.5 Conclusion.....	45
Chapter 5: To assess the impact of illegal sand mining activities on the landscape dynamics (i.e., land use change and vegetation cover change) in the study area.....	47
5.1. Introduction	47
5.2. Materials And Methods.....	49
5.2.1 Remote Sensing Data Methodology	49
5.2.2 Data Acquisition.....	50
5.2.3 Analysis of land cover change and illegal sand mining detection.....	54
5.2.4 Transition Matrix.....	55
5.3. Result and discussion	55
5.3.1. Sand mining and land-use and land cover change.....	60
5.3.2. Change Detection Matrix.....	61
5.3.3. Illegal sand mining change detection from Kei River mouth to Lubanzi River mouth along the Coast	65
5.4 Classification accuracy.....	69
5.5 Conclusion.....	70
Chapter 6: Conclusion and Recommendations	71
6.1 Introduction	71
6.2 Recommendations	73
6.3 Limitations of the Study	74
6.4 Future Research Agenda	74

References.....	76
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Together in Excellence

List of figures

Figure 1: Study area depicts the wild coast zone.....	19
Figure 2: Map representation of a spatial distribution of the vegetation cover.....	20
Figure 3: Geology map showing the local municipalities Amathole District Municipality in Eastern Cape Province, South Africa.....	22
Figure 4: Schematic representation of the workflow.....	25
Figure 5: Workflow Diagram.....	28
Figure 6: Locations of 24 sites illegal mining sites.....	31
Figure 7: Physical damage caused by illegal sand mining, and open pits used for damping and livestock fed on the dumping waste.....	33
Figure 8: Illegal sand mines near Kei Mouth/ Kei River Mouth.....	34
Figure 9: Illegal sand mining sites Colorha, Ncizela River and Ncizela 2 respectively.....	35
Figure 10: Illegal sand mining site, Kwagcaleka.....	36
Figure 11: Illegal sand mines at Ncatha 1, Ncatha 2, Ncatha 3 and KwaXambeni.....	37
Figure 12: Illegal sand mines at Kulojingqi and Ngadla River.....	38
Figure 13: Illegal sand mines at Tenza, Kwaqoqo and Kunocekedwa.....	39
Figure 14: Illegal sand mines at Plaatjie Nqabarha, Ntubeni and Dwesa Point.....	40
Figure 15: Illegal sand mines at Nkanya River, Nkanya 2, Nkanya 3 and Xhora River.....	41
Figure 16: Illegal sand mine at Mbolompo point.....	42
Figure 17: Graphical comparison 2000-2010 and 2010-2022.....	44
Figure 18: Data preparation and pre-processing flow chart.....	50

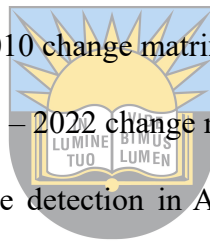
Figure 19: Land-use change dynamics of illegal sand mining.....	57
Figure 20: Land-use and land cover dynamics of illegal sand mining activities from 2000.....	58
Figure 21: Land-use and land cover dynamics of illegal sand mining activities from 2010.....	59
Figure 22: Land-use and land cover dynamics of illegal sand mining activities 2022.....	60
Figure 23: Land-use land cover change (Sqkm) of illegal sand mining activities from 2000 to 2010.....	63
Figure 24: Land-use land cover change (Sqkm) of illegal sand mining activities from 2010 to 2022.....	65
Figure 25: Illegal sand mine change detection classes between 2000 – 2020 and 2010 – 2022.....	67
Figure 26: Graphical distribution of the land-use land cover changes across the year 2000 to 2022.....	69
Figure 27: Land use land cover changes from other vegetation area coverage changes to bare soil.....	70



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List of tables

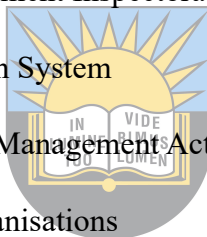
Table 1: Related studies on the sand mining along coastal zone.....	14
Table 2: The conservation and preservation status of the vegetation types along the ADM coastline.....	21
Table 3: Characteristics of the Landsat Images used for the study.....	24
Table 4: Illegal sand mining sites on the coastal area from Kei to Lubanzi River mouth.....	32
Table 5 Change detection analysis 2000-2022.....	43
Table 6: The land cover and land use classification scheme and attributes.....	51
Table 7: Land cover classes of illegal sand mining.....	56
Table 8: Sand Mining Land-use and Land Cover Change 2000,2010, and 2022.....	61
Table 9: Land class for year 2000 – 2010 change matrix.....	62
Table 10: Land class for the year 2010 – 2022 change matrix.....	64
Table 11: Illegal Sand mining change detection in Area/ Sqkm along Kei River mouth to Lubanzi River mouth.....	66
Table 12: Sand mining to other land use land cover total change to bare soil.....	68
Table 13: Accuracy assessment for validation 2000, 2010 and 2022.....	71



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List of Acronyms

ADM	Amathole District Municipality
CCA	Coastal Conservation Area
DEDEA	Department of Economic Development and Environmental Affairs
DFFE	Department of Forestry, Fisheries, and the Environment
DMR	Department of Mineral Resource
DWA	Department of Water Affairs
EA	Environmental Authorisation
EIA	Environmental Impact Assessment
EMI	Environmental Management Inspectorate
GIS	Geographic Information System
NEMA	National Environment Management Act
NGOs	Non- Government Organisations
NWA	National Water Act
MLC	Maximum Likelihood Classification
MMA	Multidimensional Map Algebra
MPRDA	Mineral and Petroleum Resources Development Act
RS	Remote Sensing
SANDF	South African National Defence Force
SAPS	South African Police Service
SMM	Sand Mine Map
UNEP	United Nations Environment Programme



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Chapter 1: Background and overview of the study

1.1 Introduction

Sand mining is universal, expanding in both developing and developed nations due to sand being abundant in rivers, lake sediments, and dunes (Larson, 2018; Padmalal & Maya, 2014). It serves various industries, such as electronics (Gavriletea, 2017), polymer production and water filtration (Geological & USGS, 2020). Sand-based materials are ubiquitous in construction, infrastructure, and everyday items like glassware and smartphones (UN Environment, 2019). Fracking relies heavily on sand extraction to recover oil from shale, further amplifying its consumption (UN Environment, 2019). According to the United Nations Environment Programme, sand is among the most heavily exploited natural resources (UNEP, 2014). An estimated 85% of the annual mineral extraction globally comprises sand and gravel (UNEP, 2014). Annually, 32–50 billion tonnes of sand and gravel are extracted from beaches, riverbeds, and quarries, primarily for electronics, glass, concrete, and asphalt manufacturing (Beiser, 2018; Bendixen et al., 2019).



Consequently, the high demand and lucrative market for sand often lead to illegal mining practices. Illegal sand mining poses a significant threat to various ecosystems, including riverine areas, dunes, forests and mangroves (Duan et al., 2019). Despite strict regulations implemented by governments, such as those in South Africa, illegal sand mining persists, driven by the lucrative returns it offers (Chilikova-Lubomirova, 2020; Green, 2012). Also, illegal sand mining is typically conducted in a decentralised, covert, and mobile manner, complicating efforts for timely detection and intervention (Chilikova-Lubomirova, 2020). Illegal sand mining is prevalent in developing nations, including Indonesia (Supriharyono, 2004; Syah & Hartuti, 2018; Widiastuti & Mote, 2018), Bangladesh (As-Syakur et al., 2012; Khan & Sugie, 2015a), Iceland (Musah & Barkarson, 2009), South Africa (Gondo et al., 2019), China, India and Vietnam (Elavenil et al., 2017; Leal Filho et al., 2021). Various motivations drive these countries' mining activities, often stemming from the need to meet socio-economic demands (Rapholo et al., 2023). Nonetheless, the escalating demand for sand poses a growing environmental challenge (PO Lawal PhD, 2011) and with it, significant environmental consequences (Asabonga et al., 2017). The impacts may vary depending on the location of the illegal activity.

Due to its scale, Debrah et al. (2014) argue that illegal sand mining falls within the broad category of Artisanal Small-Scale Sand Mining (ASM). This framework presents challenges for many governments worldwide despite being purportedly legal. For instance, although South Africa enacted the Mineral and Petroleum Resources Development Act No. 28 of 2002 to regulate mining activities (including sand mining), studies indicate minimal enforcement of environmental regulations and legislation governing sand mining operations on the country's coastline (Debrah et al., 2014; Neal et al., 2018; Pauw et al., 2018; Taljaard et al., 2019; Vetrimurugan et al., 2019). Despite governmental efforts to curb illegal sand mining, the practice persists, causing ongoing environmental harm. Effective techniques are needed to monitor and address these activities over time. Geospatial, Geographic Information System (GIS) and Remote Sensing methods offer promising approaches for this purpose, aligning with the Sustainable Development Goals (SDGs) such as climate action (13) and life on land (15) (Chaussard & Kerosky, 2016; Jie et al., 2020).

Remote sensing provides repeatable data acquisition, suitable digital formats for computer processing, and precise geo-referencing measures, making it a widely used tool for detecting, quantifying and mapping land use and vegetation changes (Chen et al., 2017). It has been extensively employed in quantifying land use changes, particularly transitions from arable land to impermeable surfaces, through using multi-temporal Landsat images (Basnet & Vodacek, 2015). The Landsat program offers current and historical data on land use and cover changes critical for monitoring and managing such changes over time (Wulder et al., 2019). Previous studies have demonstrated the efficiency and effectiveness of remote sensing and GIS techniques in monitoring and assessing sand mining activities, including mapping and quantifying sand mines (Chen et al., 2017; Duan et al., 2019; Prasad, Reddy et al., 2016). Leveraging remote sensing satellite data integrated with GIS techniques provides a comprehensive synoptic view of large areas at regular intervals, ideal for studying the extent and impact of illegal sand mining (Campbell et al., 2005).

1.2 Problem statement

The Wild Coast area of South Africa, spanning approximately 280 kilometres along South Africa's eastern coast, stands as an internationally recognised biodiversity hotspot (De Villiers, 2012; Reyers et al., 2008). Characterised by its diverse biophysical environment, the Wild Coast faces global challenges typical of many biodiverse regions, including biodiversity loss and escalating human exploitation (Castley et al., 2001; Berliner, 2011). Balancing biodiversity

conservation with the needs of local communities while preserving the area's aesthetic appeal poses a significant challenge (Simelane & Kerley, 1998; Noble et al., 2014). The demand for sand exerts pressure on the ecology of the Wild Coast due to an abundance of good quality sand in this area. As sand mining operations continue to expand, they are increasingly viewed as unsustainable due to their depletion of coastal resources and adverse environmental and social impacts (Asabonga et al., 2017; Bendixen et al., 2019; Clarke, 2018; Leal Filho et al., 2021; Subramanian, 2018). This growth in sand demand poses challenges for South Africa's government, which prioritises infrastructure development as part of its National Development Plan (NDP, 2014). The construction of houses, roads, and bridges necessitates large quantities of sand, driving further demand. However, illegal sand mining, particularly prevalent in the Eastern Cape Province and Amathole District, poses significant environmental risks without proper guidelines and permits (Matenga, 2019; Musakwa et al., 2020; Zone & Bay, 2019). The rise in housing construction along the Wild Coast exacerbates this issue, yet the full extent of the consequences remains unknown. Thus, this study seeks to elucidate the spatiotemporal trends of illegal sand mining and its impacts on the coastal landscape, aiming to inform sustainable management practices and mitigate environmental degradation.

1.3 Research aim

This research aims to assess the extent and impact of illegal sand mining activities on the coastal zone landscape dynamics of the Wild Coast of the Amathole District in the Eastern Cape, South Africa.

1.4 Research objectives

The aim was achieved through the following objectives:

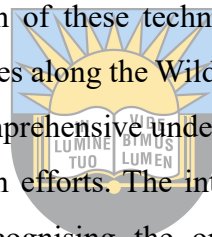
1. To evaluate the spatial and temporal trends of illegal sand mining (i.e., pit size) along the coastal zone from the Kei River mouth to the Lubanzi River mouth over the last 22 years (2000 – 2022).
2. To assess the impact of illegal sand mining activities on the landscape dynamics (i.e., land use change and vegetation cover change) in the study area.

1.5 Conceptual analytical framework

The study aims to assess the extent and impacts of illegal sand mining along the ecologically sensitive Wild Coast of South Africa, mainly focusing on its status as part of the Pondo-Albany

Thicket biodiversity hotspot, recognised as a national priority area (DWAF, 2004). The study employs two key indicators to assess illegal sand mining along the Wild Coast. Firstly, it evaluates spatial and temporal trends of illegal mining, including pit size, through analysis of historical aerial photographs and field surveys (Barbieri, 2018; Erbek, Özkan et al., 2004; Haindongo et al., 2021). Secondly, it assesses the impact of these activities on landscape dynamics, such as land use and vegetation cover changes, using Landsat images (Fu et al., 2013; Huber et al., 2002). Integration of GIS and Remote Sensing facilitates geospatial analysis and land cover change detection, relying on dense stacks of satellite imagery (Barbieri, 2018; Madasa et al., 2021).

Given the Wild Coast's status as a biodiversity hotspot hosting endemic, rare, and threatened species, scientific evidence of the impacts of illegal sand mining is crucial to inform conservation policies. Among various techniques employed in sand mining investigations, an integrated approach using Remote Sensing and GIS has proven efficient and commonly utilised. In this study, the integration of these techniques aims to enhance spatiotemporal analysis of illegal sand mining activities along the Wild Coast. Utilising multiple imaging over time across a wide area enables a comprehensive understanding of coastline dynamics, which is essential for informed conservation efforts. The integration of RS and GIS is crucial for advancing these techniques and recognising the ongoing need for development in the spatiotemporal domain.



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1.6 Significance of the study

Coastal systems, defined by Masselink & Gehrels (2014) represent the dynamic interface between land and sea, shaped by the interplay of wind, tides, waves, and currents. These environments host diverse habitats, serving as crucial transition zones between terrestrial and marine ecosystems (Masselink & Gehrels, 2014; Maun, 2009). Coastal landscapes, encompassing features like dunes, cliffs, and beaches, are interconnected and dynamic systems that have evolved through the interactions of sand, water, plants, and external forces (Haslett, 2008; Williams et al., 2018). Recognised as environmental hotspots, coastlines provide many essential services, including sediment storage, environmental regulation, and cultural and economic opportunities (Alharbi & Rangel-Buitrago, 2022; Fegley & Michel, 2021). Coastal

regions support various financial activities, such as tourism, benefiting from their unique ecological and scenic attributes (Rangel-Buitrago, 2018). Moreover, coastal landforms like beaches and dunes offer natural protection against storm threats, safeguarding inland areas from surges, inundation and erosion.

Illegal sand mining, prevalent both inland and along coastal zones worldwide, poses significant threats to these delicate ecosystems and the services they provide (Duan et al., 2019; Jordan et al., 2019; Rochayati et al., 2020; Xiao et al., 2022). In particular, the Amathole District Wild Coast Zone in South Africa's Eastern Cape Province faces detrimental consequences from illegal sand mining, including vegetation removal, land use changes, and loss of biodiversity and habitat (Frohlich et al., 2021). This study employs a combination of Landsat imagery, aerial photography, and field surveys to identify, map, and quantify illegal sand mining sites over time, further examining their impact on land use and land cover changes. By contributing to achieving Sustainable Development Goals such as Climate Action (13) and Life on Land (15), the findings of this study can inform decision-making processes for environmental managers and policymakers. Departments like the Department of Economic Development and Environmental Affairs (DEDEA), the Department of Mineral Resources (DMR), the Department of Water and Sanitation (DWS), and the National Department of Environment, Forestry and Fisheries (DFFE) can utilise this information to develop effective strategies and regulations for managing illegal sand mining. Additionally, the study provides valuable baseline data for implementing bylaws, especially concerning small-scale sand mining, and identifying hotspots of illegal activity in the Amathole Wild Coast region.

1.7 Dissertation layout

The dissertation unfolds across six chapters, organised to avoid redundancy and ensure coherence. Chapter one is an introduction, offering the contextual background on illegal sand mining. It delves into the causes and impacts of this pervasive issue while introducing the methodologies utilised in similar studies. This chapter highlights the global and national scope of illegal sand mining and outlines the conceptual, analytical framework, problem statement, research aims and objectives, significance, and conclusion. Transitioning into the second chapter, the focus shifts towards a detailed exploration of sand mining, its challenges, and contributions from various countries. The tools of remote sensing and geographical information systems are underscored for their utility in monitoring sand mining activities. Additionally, this chapter examines relevant legislation and scrutinises previous studies conducted in coastal

zones. Chapter three offers a deep dive into the study area, thoroughly describing its geographical, socioeconomic, and environmental characteristics. This section also outlines the chosen quantitative methodology, accompanied by a flowchart of the research strategy and ethical considerations. In chapter four, the study's findings are presented, demonstrating how aerial photographs and field surveys can effectively identify illegal mining sites and assess trends over time. Structured in a traditional paper format, this chapter encompasses titles, introductions, methods and materials, results, discussion and conclusions. Chapter five delves into the impact of illegal sand mining on land use and land cover changes, utilising Landsat imagery and remote sensing techniques. Presented in paper format, this section offers insights into the transformative effects of illegal sand mining on coastal landscapes. Finally, chapter six brings the dissertation to a close with a summary, conclusion, and recommendations. This section encapsulates the key findings, offers actionable recommendations, acknowledges limitations, and outlines avenues for future research.



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Chapter 2: Literature review

2.1 Introduction

Over the past few decades, the demand for sand has surged dramatically, driven by its diverse applications across industrial, environmental, and tourism sectors (Rentier & Cammeraat, 2022). This surge has triggered a global increase in sand mining activities, often conducted with scant regard for environmental regulations, thereby posing significant environmental challenges (Madyise, 2013; Malebana, 2021). Sand, a crucial natural resource, finds application in various sectors, making it one of the most utilised resources worldwide (Bhardwaj & Kumar, 2017; Gallagher & Peduzzi, 2019). Factors such as global population growth, rising living standards, and rapid urbanisation further exacerbate the demand for sand (Gavriletea, 2017; Leal Filho et al., 2021; Torres et al., 2017), with sand and gravel accounting for 85% of global mineral extraction annually (UNEP-GEAS, 2014; Peduzzi, 2014).

This escalating demand has positioned sand as a critical natural resource, particularly evident in the fracking sector, where vast quantities of frack sand are indispensable for oil extraction from shale (Filip & Filip, 2020). Illegal sand mining poses a significant challenge globally, with both natural and human-related factors contributing to its proliferation (Asabonga et al., 2017; Ashraf et al., 2011; Duan et al., 2019). Coastal areas are particularly vulnerable, facing increased degradation due to urbanisation and exposure to climate change-induced threats (Doody, 2004). Dunes, acting as coastal buffers, find themselves trapped between human pressures on land and climate change impacts at sea, leading to shoreline retreat and erosion (Jordan et al., 2019). Anthropogenic alterations such as jetty construction, shoreline armouring, and sand extraction exacerbate these challenges, disrupting coastal sediment budgets and exacerbating coastal erosion (Rochayati et al., 2020). Coastal sand mining, in particular, disrupts sediment dynamics, negatively impacting aquatic habitats and increasing water turbidity (Jonah et al., 2015). The practice is rampant in various regions, contributing to coastal ecosystem degradation and threatening species extinction (Ayyam et al., 2019; Numbere, 2018). Furthermore, sand mining affects groundwater recharge, raising water costs and exacerbating water insecurity (Wu et al., 2013). Ongoing pit sand mining leads to riparian vegetation degradation and poses hazards to wildlife and human safety (Husain et al., 2017; Madyise, 2013).

Remote Sensing (RS) and Geographic Information Systems (GIS) have emerged as indispensable tools for monitoring and assessing the impact of illegal coastal sand mining on a

regional and global scale (Mahrad et al., 2020; Parthasarathy & Natesan, 2015). These technologies enable the identification of coastal hotspots and guide micro-managing decisions along the coastal zone (Jonah et al., 2015; Muhammad Aqeel Ashraf et al., 2011). However, the lack of adequate regulatory frameworks and enforcement mechanisms has fuelled illegal sand mining activities, necessitating a comprehensive assessment of the extent and impact of illegal sand mining activities and their linkage to existing legal frameworks and rehabilitation efforts (Gavriletea, 2017).

2.2 Positive and negative impacts of global sand mining and its associated activities

The sand mining sector plays a vital role in driving economic growth, with sand exports contributing to job creation and investments in mining regions (Katz-Lavigne et al., 2022). Qatar, for instance, emerged as the world's largest importer of sand and gravel in 2012, with imports valued at nearly \$6.5 billion, while the United Arab Emirates recorded imports worth approximately \$456 million in 2014 (Gavriletea, 2017; Sonna et al., 2022). Despite its economic significance, the escalating use and extraction of sand have led to adverse environmental impacts at both local and global levels, necessitating urgent intervention to mitigate these consequences (Gavriletea, 2017; Leal Filho et al., 2021; Muhammad Aqeel Ashraf et al., 2011; Torres et al., 2017). The Asia-Pacific region has witnessed the highest extraction rates, followed by Europe and North America, with global sand mining reaching around 11 billion tonnes in 2010 solely for construction purposes (Gavriletea, 2017; Leal Filho et al., 2021; Torres et al., 2017). In the United States alone, construction sand and gravel usage and production amounted to an estimated \$8.9 billion in 2016, reflecting a 24% increase over the previous five years (Torres et al., 2017; Zartner, 2020). However, many developing and underdeveloped nations engage in illegal sand mining activities, leading to various adverse environmental consequences (Gavriletea, 2017; Padmalal & Maya, 2014). Primary sand and gravel producers include the United States, the Netherlands, Spain, Turkey, and India, while top importers comprise Germany, Belgium, Singapore, Luxembourg, Canada, and China (Johnson & Noguera, 2012; Kearney & Policy, 2006).

2.3 Legislations pertaining to sand mining in South Africa

In South Africa, the primary regulatory authorities overseeing sand mining include the Department of Mineral Resources (DMR), the Department of Forestry, Fisheries, and the Environment (DFFE), and the Department of Water Affairs and Sanitation (DWS). While various researchers have discussed the legislative framework surrounding sand mining (Chevallier, 2014; Mkhize, 2017), more research is needed on the specific legislations and regulations triggered by legal and illegal sand mining activities. Sand mining operations involve topsoil clearance, tree removal, root uprooting, vehicular access to operation sites, and landscape alteration, all of which may invoke different coastal, water, mineral, biodiversity, environmental, and land legislations.

The primary legislation guiding sand mining activities and operations in South Africa is the Mineral and Petroleum Resources Development Act 28 of 2002, under which the DMR holds jurisdiction over sand mining. This act is the principal legislation governing the country's natural resources and development processes, providing state control over all mineral resources, including unprocessed sand. It establishes a comprehensive regulatory framework for mineral resource exploitation, managed through various rights, approvals, and permits. Under this act, any individual intending to extract natural sand must apply to the DMR for a license before commencing activities. Failure to obtain such a permit constitutes a violation of the legislation. Another legislation that sand mining activities may trigger is the National Environmental Management Act 107 of 1998, the primary legislation governing environmental management in South Africa. Relevant sections include 2.24 and 2.25, covering ecological principles, environmental impact assessments, and duty of care provisions. Sand mining's adverse environmental impacts, such as biodiversity loss, riverbank collapse, riverbed deepening, sinking shorelines, and coastal erosion, necessitate compliance with ecological principles to minimise and restore these effects. The Act also mandates monitoring and enforcing compliance with environmental laws at all levels of government to mitigate the environmental harm caused by illegal sand mining activities.

Additionally, sand miners may be subject to the provisions of the National Water Act 36 of 1998 if they utilise water in their operations. To prevent adverse effects on river courses or estuaries, sand miners must ensure that their activities do not impact the stability of these water bodies, thereby avoiding erosion, sedimentation, and vegetation shifts that could harm riparian ecosystems. The Act also imposes environmental controls to prevent water contamination from

chemicals, oil, grease, and other pollutants. Any sand miner intending to use water must obtain a water use license, following the application process outlined in Section 41 of the National Water Act. This license allows the lawful use of water resources for mining purposes while ensuring compliance with regulations to protect these resources. Adherence to these legislative frameworks is essential to ensure sustainable sand mining practices while minimising environmental degradation and protecting vital natural resources.

2.4 Reporting on illegal sand mining along the Wild Coast

On August 21, 2014, The Daily Dispatch News shed light on illegal sand mining activities along the Wild Coast, highlighting the motivations driving these illicit operations and the resultant consequences on the local community and environment. The primary motivation cited for these activities was the prospect of income. Still, the environmental destruction caused severe harm to both the ecosystem and the community's livelihoods, including livestock damage. Concurrently, The Cape Point Chronicle reported the successful apprehension of an illegal sand mining syndicate in the Western Cape on the same day, emphasising the ongoing battle against illegal mining operations (<https://www.capepointchronicle.co.za/2014/08/21/illegal-sand-miners-caught-green-scorpions/>).



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In September of 2013, African Budget Safari reported extensively on the long-term effects of unlawful dune and sand mining along the Wild Coast (<https://www.africanbudgetsafaris.com/blog/destroying-the-wild-coast-stop-the-illegal-sand-mining-crisis/>). These reports, among others, underscore the extensive nature of the illegal sand mining issue in South Africa and the resulting damage. According to The African Budget Safari, the Department of Economic Development, Environmental Affairs, and Tourism (DEDEAT) responded to the illegal sand mining by creating an environmental management plan for the Wild Coast, signalling a positive step in addressing the problem. Joint operations targeting illegal sand mining activities in the Komati River were conducted by the Department of Home Affairs (DHA), the Department of Water and Sanitation (DWS), the South African Police Service (SAPS), and the Department of Mineral Resources and Energy (DMRE), as reported by Lowvelder. These operations aimed to arrest perpetrators and confiscate their equipment, with a joint inquiry conducted on August 19 and 20, 2020 (<https://lowvelder.co.za/722736/sand-miners-continue-their-illegal-activities/>). Although there

were delays attributed to logistical challenges and the implementation of the Prevention of Organized Crime Act No 121 of 1998, the process persisted, driven by intelligence-driven joint operations along the coastline. An officer from the DMR highlighted that illegal miners were well-equipped with advanced heavy machinery, posing a significant threat to the ecosystem near the Komati River in Mpumalanga. The effects of riverine sand mining on freshwater ecosystems include riverbank collapse, loss of native flora, and degradation of the estuarine environment. Community members were encouraged to play a role in halting illegal sand mining operations by reporting them to relevant authorities rather than engaging in physical confrontations. This collaborative approach ensures that offenders are caught in the act, strengthening the evidence against them. The joint task team must garner support from essential stakeholders and local communities to combat illicit sand mining activities effectively.

In a crackdown to deter unauthorised sand miners from the Umvoti River, the National Department of Water and Sanitation (DWS), the iLembe District Municipality (IDM), SAPS, and media representatives conducted a coordinated effort. They visited multiple illegal sand mining sites to assess activities, impound equipment if necessary, and clear riverbank blockages resulting from overexploitation of sand mining (<https://northcoastcourier.co.za/29300/sand-mining-blitz-sweeps-through-the-mvoti/>).

Although government efforts to address the issue have faced challenges, authorities are committed to enforcing the law and ensuring ongoing rehabilitation of affected rivers. Legal action, including fines and potential jail terms, awaits illegal sand miners, highlighting the seriousness of the issue. The focus is now on cleaning up rivers with severe sand mining problems, such as the Mhlathi, Illovo, Umgeni, Mhlathuze, and Amatigulu rivers in KwaZulu Natal.

2.5 Coastal sand mining in South Africa: An overview

Numerous studies have linked the significant activity of coastal sand mining to the retreat of the shoreline and deterioration of beach conditions along South Africa's coastline (Amponsah-Dacosta & Mathada, 2017; Asabonga et al., 2017; Mepaiyeda et al., 2020; Pauw et al., 2018; Vetrimurugan et al., 2019). Despite existing environmental regulations and legislation governing the coastal marine environment in various sector-based government departments, research indicates a lack of enforcement concerning the types and extent of sand mining operations (Neal et al., 2018; Pauw et al., 2018; Taljaard et al., 2019; Vetrimurugan et al., 2019).

A study on the Namaqualand region of South Africa's coastal mineral sand mine evaluated the long-term success of experimental rehabilitation efforts. Findings revealed that despite patchy vegetation immediately after backfilling and processing the soil seed bank, rehabilitation goals in the area must be achieved (Pauw et al., 2018). Similar discoveries were made by Norman et al. (2006) regarding the regeneration of Western Australian jarrah forests post-sand mining, highlighting seeding as a high-impact and cost-effective rehabilitation approach. However, this technique necessitates comprehensive seed management and collection infrastructure, including technologies for dormancy-breaking and seed enhancement (Mayence et al., 2017).

Studies conducted at the Namakwa Sands mines in Brand-se-Baai, South Africa, aimed to develop rehabilitation techniques suitable for local environmental conditions (Mahood, 2003). These techniques included topsoil replacement, seed sowing, and transplantation of natural plants (Mahood, 2003). Furthermore, experiments combining these practices were carried out in 2008, anticipating more rapid vegetation recovery to its natural state compared to individual treatments (Blood, 2006). Despite insights from earlier studies into the potential effects of unlawful sand mining, the linkage between the existing legal framework, enforcement guidelines, and rehabilitation before and after mining on landscape dynamics and land use change remains poorly understood, particularly in South Africa's coastal zones and associated environmental effects (Ferreira et al., 2016; Madyise, 2013). The environmental effects of sand mining vary depending on where it is practised, with pits, rivers, and the sea being the primary natural sources of sand (Padmalal & Maya, 2014). Illegal sand mining and transportation practices worldwide have exacerbated the environmental effects of legal mining and sourcing (Bhattacharya & Chatterjee, 2021; Gallagher & Peduzzi, 2019).

2.6 Coastal vulnerability due to sand mining

The use of coastal sand mining for construction materials is on the rise, leading to devastating impacts on marine life and coastal habitats, which puts the world's population at risk of a sand crisis (Padmalal & Maya, 2014; Gavriletea, 2017; Gallagher & Peduzzi, 2019). Globally, sand mines are being overexploited, resulting in environmental harm, community vulnerability, resource shortages, and violent conflicts. Sand extraction occurs on a vast scale for purposes such as shale gas extraction, beach nourishment projects, and land reclamation, further exacerbating the situation (Spanier & Zviely, 2022). The increasing scarcity of sand and gravel, primarily used in road construction, building infrastructure, electronics, and glass manufacturing, is a growing concern worldwide (Bisht, 2022; Gallagher & Peduzzi, 2019). For

instance, local sand usage in Vietnam surpasses the country's total sand deposits, raising alarms about potential shortages by 2030, according to the Ministry of Construction (Cousins, 2019). Recent floods in Bangladesh, India, and Houston have further heightened the global demand for sand (Torres et al., 2017). Sand mining negatively impacts livelihoods, as coastal communities are increasingly vulnerable to floods and storm surges due to erosion caused by heavy sand mining (Bal, 2021). The 2004 Indian Ocean tsunami's impacts on Sri Lanka were exacerbated by sand mining, constituting about a third of the country's total sand demand, highlighting its detrimental environmental effects (Padmalal & Maya, 2014; Wickramasinghe, 2021). Similarly, sand mining in Vietnam's Mekong River Delta jeopardises the delta's long-term viability by reducing sediment supplies, posing risks to water and food security (Park et al., 2020).

Illegal sand mining activities devastate natural landscapes and impact local communities. Along the Wild Coast, unlawful sand excavation transforms spectacular dune fields into wastelands, eroding coastal protection areas and causing soil erosion, road damage, and loss of natural vegetation (Park et al., 2020). Balancing the region's development needs with environmental protection is crucial to mitigate irreversible harm to biodiversity and estuarine environments caused by illegal sand mining activities (Park et al., 2020). To address the issue, governments need to undertake extensive educational awareness campaigns on coastal erosion and its impacts while implementing evidence-based regulations and enforcement measures (Adem Esmail & Suleiman, 2020; Williams et al., 2018). However, there is a lack of sustained guidelines and legal frameworks regarding the Environmental Impact Assessment of sand mining operations (Koehnken et al., 2020; Smandych & Kueneman, 2013). The study emphasises the importance of organised networked governance to address unlawful sand mining activities and promote sustainable development (Chevallier, 2014; Mkhize, 2017; Rochayati et al., 2020). By adopting a conglomerate approach, integrating social, local, and climate policies into national strategies for environmental protection and sustainable development becomes feasible, reinforcing the urgent need for collective action to safeguard coastal resources and ecosystems.

Table 1: Related studies on the sand mining along the coastal zone

S/N	Country	Data Source (Models, variables, and techniques)	Findings/Gaps	References
1.	Tanzania	A case study approach	Illegal sand mining is prevalent in both coastal and mainland areas. Accelerated and localised coastal erosion leads to environmental degradation and poses a health risk due to the collection of water in eroded areas, providing a breeding ground for the malaria vector. Formulating policies and strengthening governance, along with educational campaigns, can assist in eliminating the issue.	(Masalu, 2002)
2.	Indonesia	A descriptive qualitative and mining approach, propulsive and sampling technique	Disastrous consequences on the physical environment while there is a positive socio-economic impact on the community. An environmental management plan is necessary to preserve and maintain the coastal ecosystem and prevent worsening impacts on the coastline. There is a need for more education on the issue due to a lack of understanding observed.	(Rochayati et al., 2020)
3.	Ghana	A qualitative approach, maximal variation sampling	Drivers for illegal coastal sand mining included the profitability of the business and the improvement to livelihood., resistance to change, abundance of the resource, and lack of law enforcement. Endemic corruption should be dealt with, and there is a need for improvement in law enforcement	(Mensah & Mattah, 2023)

4.	Bangladesh	A qualitative approach	Local influential residents illegally privatised sand mining (Khan & Sugie, 2015b) Homesteads located along the riverbank run the risk of losing their property due to the mining. Environments were compromised, and individual wealth was pursued at the expense of the local communities.
5.	Global	A qualitative approach with a focus on policy	There is a plethora of factors that lead to illegal sand mining globally along beaches. (Rangel-Buitrago et al., 2023) Multiple approaches and technological advances have been devised to reduce the impacts of sand mining in coastal environments. Illegal sand mining could be reduced if governments established stronger regulations and penalties while incentivising industries that minimise sand use. Regulation is not always easy, especially in developing countries where governments have other priorities and need more resources.
6.	South Africa	Qualitative approach	Illegal soil extraction has negatively affected the livelihood of residents in the Umdoni Municipality, and the environment has been destroyed. (Shange et al., 2023) The sand mined is mainly used in construction. A lack of law enforcement by local authorities has resulted in illegal activities continuing despite legislation being put in place.
7.	Tanzania	Qualitative surveying and quantitative	Islands closer to the shore in some of the sampled areas had

entirely disappeared due to the extensive illegal sand mining.

Water is encroaching and destabilising homes, along with a loss in vegetation.

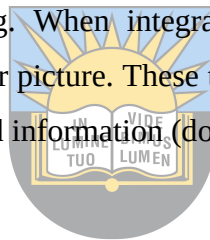
In another village, power lines had been compromised, and residents faced threats and intimidation from the miners, posing a safety risk.

Some sites require no permit, allowing miners to enter areas without regulation.

8.	South Africa	Published articles, unpublished reports, strategic government-based documents, print media, newspapers, magazines, and relevant government departments	The systematic deprivation of coastal access for the African majority in South Africa has been carried out through a variety of laws, indicating that the country's history of Apartheid continues to make it difficult for people to access coastal resources. A significant change in spatial planning and socioeconomic growth was required to correct the colonial era's inequities. To correct historical imbalances, the findings recommend that in addition to addressing the government's need to rethink town planning and address the issue of exclusive use of coastal resources and expropriate properties for public use.	(Mafumbu et al, 2022)
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2.7 Remote Sensing and Geographical Information Systems in monitoring illegal sand mining

Among the investigations conducted into sand mining, various techniques have been employed to monitor these activities, with one of the most efficient and commonly used methods being the integration of Remote Sensing (RS) and Geographical Information Systems (GIS). Remote sensing, a geospatial technique, enables data collection without physical contact (Horning, 2008). Area monitoring is crucial in monitoring illegal sand mining, which can be achieved through spatio-temporal techniques. Remote sensing offers high spatial resolutions, providing accuracy over large areas, with higher resolution images enabling more detailed analysis (Rapholo et al., 2023). Remote sensors can be passive or active, with active sensors capable of generating their signal, while passive sensors measure solar energy reflected or emitted from the Earth's surface (Horning, 2008). For monitoring illegal sand mining along coastlines, high-fine spatial resolution images, such as those from Landsat and Sentinel-2 sensors, are essential (Wang et al., 2013). However, RS techniques alone may not provide a comprehensive understanding of the extent of damage caused by illegal sand mining. When integrated with RS techniques, Geographic Information Techniques can offer a fuller picture. These techniques involve the use of computer systems to analyse geographically tagged information (dos Santos Alves et al., 2020).

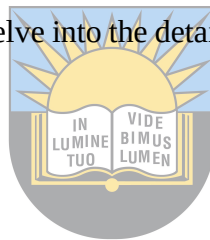


The integration of Geographical Information Systems and Remote Sensing helps advance spatiotemporal techniques necessary for analysing coastlines and the impacts of illegal sand mining activities (Swain, 2005). A more precise and accurate picture of coastline progression, including erosion and vegetative changes, can be obtained by utilising multiple imaging over time across a vast area. The integration of RS and GIS was crucial for advancing these techniques, given the ongoing development needed in the spatio-temporal space with individual techniques. The Normalized Difference Vegetation Index (NDVI), widely used in remote sensing, measures vegetation density and assesses changes in plant health (Viana et al., 2019). This index can be applied to monitor illegal sand mining, as it directly reflects the effects of sand mining on plant health and density, serving as a measure of the extent of these effects. While monitoring illegal sand mining is expected to become more accessible with advancements in geographical technologies, expert monitoring using RS and GIS can help mitigate the effects. Additionally, community involvement in monitoring illegal activities and tighter government regulations can make a significant difference in curbing these activities.

Chapter 3: Study area and research design

3.1 Introduction

The investigation centred on the Wild Coast region within the Amathole District of the Eastern Cape Province, South Africa, serving as a case study for illegal sand mining activities. Specifically, attention was focused on the coastal strip extending 3 kilometres from the high-water mark inland. This delineated area was selected based on both coastal activity regulations, which cover illegal sand mining, and a comprehensive understanding of the characteristics of the study area. Illegal sand mining has visibly altered the coastal landscape, adversely affecting the surrounding forest, dune forest, and grassland ecosystems. To provide context, the chapter offers insights into the research region, including its population demographics, socioeconomic status, coastal vegetation, and geological features. Understanding these factors is crucial as they indirectly influence illegal sand mining activities. Furthermore, the chapter outlines the research design employed to achieve the study's objectives. Subsequent chapters, mainly Chapter Four and Chapter Five, will delve into the detailed methodology used for each specific objective.



3.2 Study area

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The study area is situated within the Amathole District Municipality (ADM) on the southeastern side of the Eastern Cape Province of South Africa (see Figure 1). This municipality lies at the centre of the province, with an elevation of 1,963 m (6,440 ft), bordered by the Indian Ocean at 32° 34' 29.990 S and 27° 12' 17.400 E, and holds a total population of 892,637 (StatSA, 2016). Covering a land area of 23,577 km² (StatSA, 2016), the district stretches along the Sunshine Coast from the mouth of the Fish River to the Eastern Seaboard and along the Wild Coast to just south of Hole in the Wall. However, the study is focused solely on the Wild Coast of the Amathole District, spanning from the mouth of the Kei River to the mouth of the Lubanzi River.

The ADM comprises six local municipalities: Raymond Mhlaba, Ngqushwa, Great Kei, Mbhashe, Mnquma, and Amahlathi. It is characterised by the Amathole mountain range, vast undulating grasslands, valley vegetation, pristine estuaries, picturesque beaches, forests, and waterfalls (ADM, 2017). The region experiences a subtropical climate, with summers being

the wettest season (ADM, 2017). According to the ADM Wetland Report of 2017 and Benhin's (2008) study, the average annual rainfall is 400 mm, though it may range from 700 to 1000 mm in certain areas (Benhin, 2008).

Additionally, the average monthly temperature varies from 15°C to 25°C, with winter temperatures averaging 21°C and summer temperatures reaching 28°C. As per the ADM Integrated Development Plan (2012), a disproportionately high number of forest species in this biome are rare or endangered, making it the second richest in terms of biodiversity per unit area in South Africa.

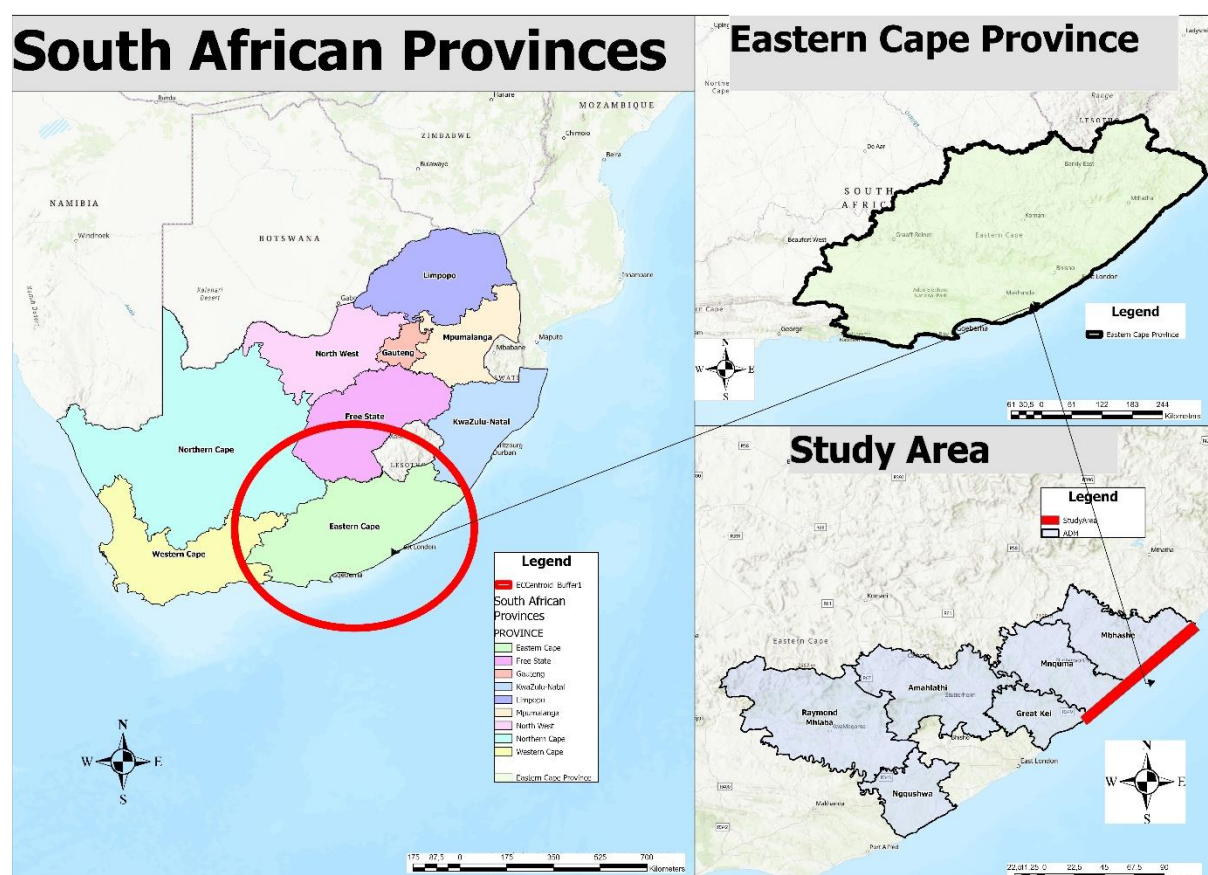


Figure 1: The study area depicts the Wild Coast zone from the Kei River mouth to the Lubanzi River mouth. The shaded area is from the high water to about 3 kilometres inland.

3.3 Coastline vegetation

Table 2 presents the vegetation classifications in the Amathole District Municipality (ADM) along the coast and their conservation and preservation status (Mucina & Rutherford, 2006). Consequently, two biomes dominate the ADM: savannah and grassland (Becker, Coetsee, Cowling, & Potts, 2015), while the coast is primarily characterised by forest species and grassland (Von Maltitz et al., 2003). The savannah habitat prevails in the eastern municipalities, while the grassland biome dominates the inland areas from Mbhashe to Raymond Mhlaba local municipality. It is mainly found on flat and undulating terrain and includes the escarpment. Albany thicket covers Ngqushwa, Raymond Mhlaba, and the Great Kei Local Municipalities' coasts (Mucina & Rutherford, 2006). The Albany thicket exhibits mixed forest and savannah biomes (Becker et al., 2015). Evergreen low forests and confined shrubland with sclerophyllous or succulent trees, shrubs, and vines, the majority of which have spiky stems, dominate this biome (Mucina & Rutherford, 2006). The Indian Ocean Coastal Belt dominates the eastern coastlines of the Mquma and Mbhashe Local Municipalities, stretching from the Kei River to the Lubanzi River, where the research was conducted (see Figure 2).

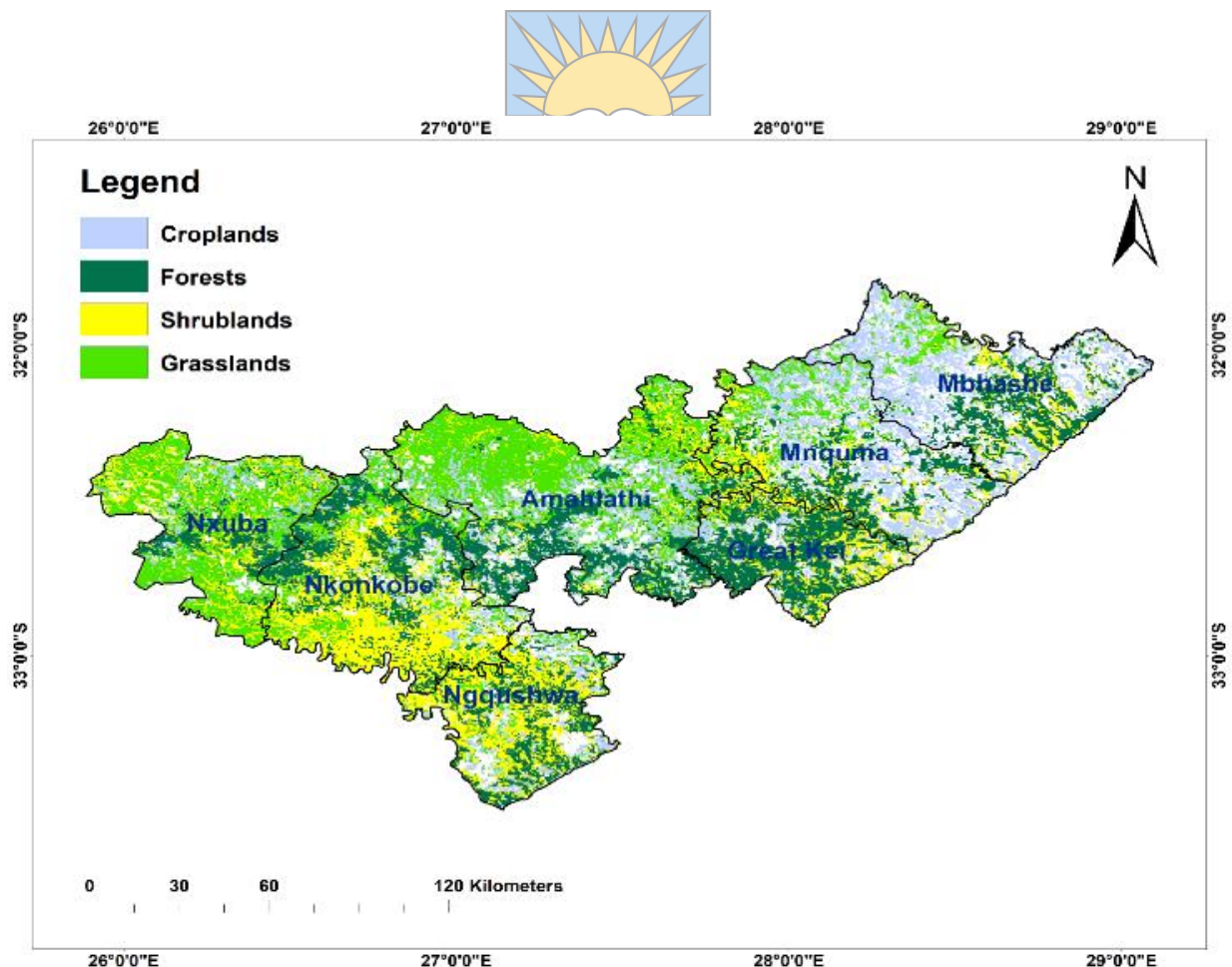


Figure 2: Map showing the spatial distribution of vegetation cover.

Table 2: The conservation and preservation status of the vegetation types along the ADM coastline (Mucina and Rutherford, 2006)

Biome	Vegetation type	Conservation status	Description of protected status
Azonal vegetation	Albany Dune Strandveld	Least threatened	Well protected
	Cape Seashore Vegetation	Least threatened	Well protected
Waterbodies	Cape Coastal Lagoons	N/A	N/A
Forest	Southern Coastal Forest	Least threatened	Well protected
Indian Ocean Coastal Belt	Transkei Coastal Belt	Vulnerable	Hardly protected

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3.4 Geology

Figure 3 illustrates the geology of the area from the high-water mark to the inland areas along the Wild coastal zone in the Amathole District Municipality, Eastern Cape Province, South Africa. The water and land between the low and high-water marks to the inland areas encompass land demarcated as admiralty reserve, government reserve, beach reserve, and coastal forest reserve (ADM, 2012; DEA, 2014). The land area extends 1 km inland from the inland boundary of the coastal public property in non-urban areas and 100 m from the high-water mark in urban areas where development and activities are strictly controlled (Sink et al., 2012). Furthermore, the Middleton and Balfour Formations of the Karoo Supergroup dominate the ADM Wild coastal zone, with widespread dolerite intrusions (Nolte et al., 2021). According to (Mepaiyeda et al., 2020), the Karoo Supergroup in the Eastern Cape Province of South Africa

began with the deposition of the glaciomarine sediments of the Dwyka Group, with a stratigraphic thickness of about 600 m to 700 m.

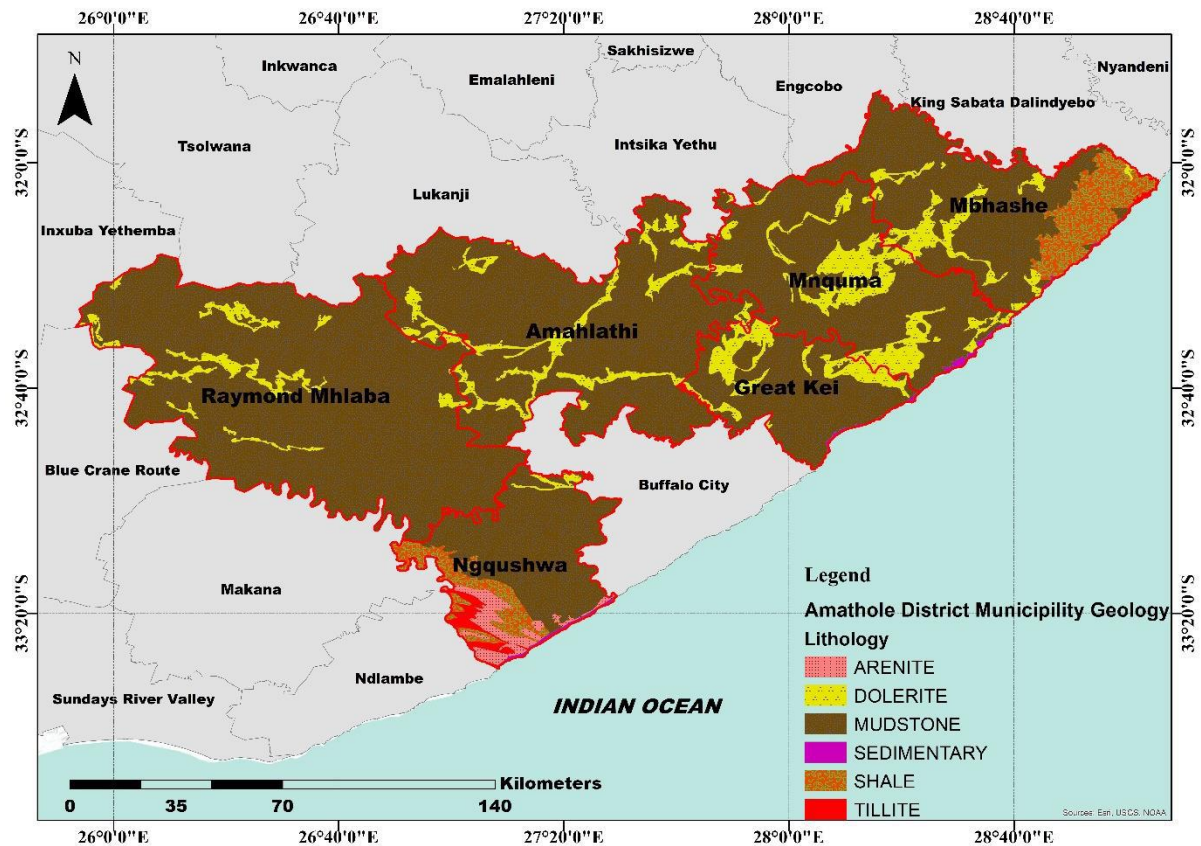


Figure 3: Geology map showing the local municipalities Amathole District Municipality in Eastern Cape Province, South Africa

3.5 Research design

This research employed quantitative research methods to investigate the phenomenon of illegal sand mining. Quantitative research involves gathering and analysing numerical data using mathematical techniques, such as statistical data representation (Creswell & Creswell, 2017). The study utilised spatio-temporal quantitative research methods to assess the extent and impact of illegal sand mining, leveraging GIS and Remote Sensing techniques to aid in the research process (Huber et al., 2002). Previous studies have demonstrated that very high-resolution aerial imagery can effectively be used for mapping sand mining activities (Martín-Velázquez et al., 2022). Additionally, quantitative methods were employed during field surveys, or ground-truthing, to identify and locate illegal sand mines, complemented by the

physiographical knowledge of the study area. Similar studies have successfully adopted this approach to monitor illegal sand mining activities (Gruel & Latrubesse, 2021; Duan et al., 2019).

3.5.1 Data collection for objective 1

Ground truthing was conducted in the study area in July 2023, focusing on specific areas of interest due to the vast size of the study area. This proved to be a challenging exercise given the area's remote nature and the roads' poor condition, some of which required 4X4 vehicles for access. Data collection primarily centred on gathering GPS coordinates and capturing photographs of the mined areas. The purpose of ground-truthing was to enhance the overall analysis and interpretation of the acquired data, as well as to validate the information gathered during desktop analysis (Lillesand et al., 2015). This process involves collecting information about the study area through field surveys, analysing aerial photographs or high spatial resolution data, and drawing on personal experience (Campbell & Wynne, 2011). Additionally, historical knowledge of the study area was utilised to inform the ground truthing process. Furthermore, the analysis was conducted using aerial photographs from the National Department of Rural Development: Chief Directorate National Geographic Information spanning 2000 to 2022.



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3.5.2 Data collection for objective 2

The data utilised in this study was gathered from various sources to enhance the accuracy of its findings. Different types of satellite imagery were employed to assess the impact of illegal sand mining activities on landscape dynamics, explicitly focusing on land use change and vegetation cover change within the study area.

Among the available satellite imagery options, Landsat imagery was preferred due to its temporal resolution and the availability of near and mid-infrared bands, which enable detailed examination of vegetation and landscape features (Das & Singh, 2013). Landsat 5 (TM), Landsat 7 (ETM+), and Landsat 8 (OLI) satellites were selected for this study based on their quality and availability. The images chosen were captured during the same seasonal period to minimise the effects of seasonal variation and varying sun positions. Table 3 provides a detailed overview of the data characteristics utilised in this study.

Table 3: Characteristics of the Landsat Images used for the study.

Satellite	Sensor	Path/Row	Spatial Resolution(m)	Date of acquisition
Landsat 5	TM	169/082 169/083	30	23/08/2022
Landsat 7	ETM+	169/082 169/083	30	23/08/2022
Landsat 8	OLI	169/082 169/083	30	23/08/2022

3.5.3 Flowchart adopted for the research design

An integrated analytical framework was employed to conduct this study, aligning with the specific objectives outlined in the research design, as depicted in Figure 4. The conceptual, analytical framework adopted incorporates remote sensing and GIS methodologies to analyse the extent and impacts of illegal sand mining along the Amathole District Wild coastal zone (Figure 4).

Remote sensing and GIS-based techniques were utilised to analyse spatiotemporal trends in illegal sand mining activities, focusing on landscape dynamics and identifying hotspots to guide enforcement and rehabilitation efforts along the coastal zone. Furthermore, this research design includes a schematic representation of the workflow that supports this research, as illustrated in Figure 4.

3.6 Ethical Consideration

The University of Fort Hare's Research Ethics Committee (UREC) granted the student ethical clearance on 25 September 2022. The reference number for clearance is NEL031SDAN01 (REC-270710-028-RA Level 01). To this purpose, all the requirements were met. Furthermore, the authors of all published materials were duly credited, and the analysis adhered to pre-proven methodologies, lending validity to the study's conclusions.

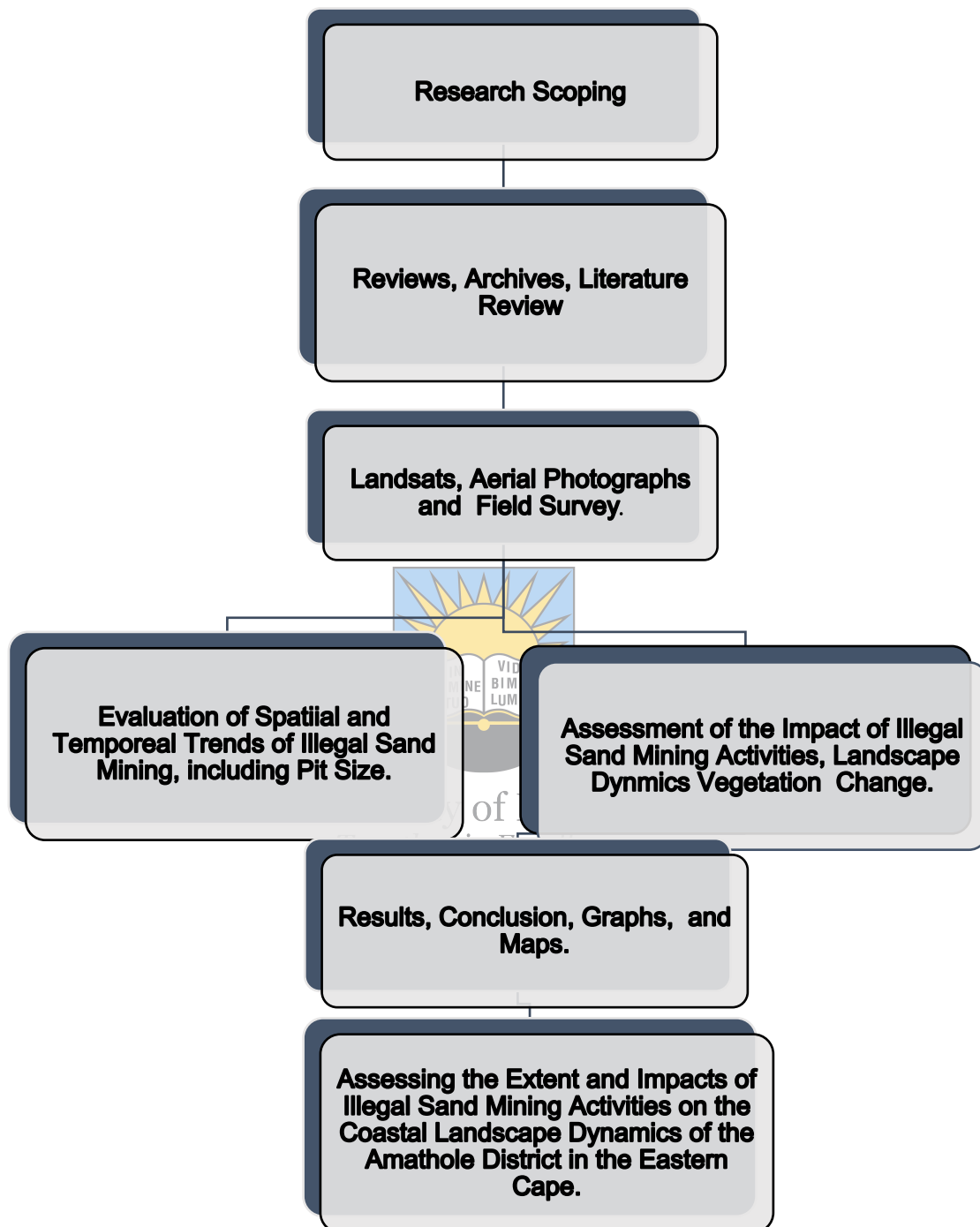


Figure 4: Schematic representation of the workflow.

Chapter 4: Assessment of spatiotemporal trends of illegal sand mining (i.e., pit size) along the coastal zone from Kei River mouth and Lubanzi River mouth.

4.1. Introduction

Illegal sand mining, performed on inland dunes, beaches and riverbeds, often employs open pit techniques and large machinery to extract sand deposits, clear vegetation, and create access roads for truck conveyance (Ayyam et al., 2019; Chevallier, 2014; Pilkey, Longo, & Neal, 2023). The extracted sand is then conveyed and privately supplied to nearby businesses (Douglas, 2012). This practice is lucrative as most illegal miners collect sand for free from neighbouring sandbanks, inland dunes, and major river routes, resulting in the removal of crucial riparian vegetation and the damage of ecosystems that stabilise the environment. Although illegal sand exploitation may seem limited and localised, these operations constantly shift locations, leaving behind barren and disturbed lands (Łabuz, 2014; Pearson, 2017).

Illegal sand mining is a significant contributor to beach erosion, affecting sediment delivery by rivers to coastal zones and harming surrounding biota (McLachlan et al., 2013; Nyame & Grant, 2014; Padmalal & Maya, 2014). Moreover, it adversely impacts marine ecosystems by increasing water turbidity, reducing water clarity, and damaging fish reproductive grounds globally (Gebremedhin et al., 2018; Mummad Aqeel Ashraf et al., 2011; Rentier & Cammeraat, 2022). This phenomenon is prevalent in most industrialised and developing countries due to the high suitability of yellow sand found in river and lake sediments for various uses (Firdaus & Nakagoshi, 2013; Ghosh et al., 2016; Meng et al., 2018). However, many developing countries lack significant regulatory initiatives to curb unlawful mining, leading to threats to rivers and coastlines worldwide (Gavriletea, 2017; Visseren-Hamakers & Glasbergen, 2007).

Remote sensing techniques have been effectively utilised to monitor illegal sand mining operations due to their broad coverage and ease of data collection (Cho & Kao, 2022; Duan et al., 2019; Zhu, 2020). These methods have provided valuable insights into detecting illegal sand mining and its environmental impacts across various regions globally (Azhar et al., 2020; Cho & Kao, 2022; Cooray & Gamage, 2016; Upadhyay, 2019; Zhu, 2020). The results of such studies support governmental oversight and management of illegal sand mining operations and offer guidance for water bodies in any region.

To address the collapse of marine ecosystems and riverbank constructions caused by illegal sand mining, adequate monitoring is essential to identify long-term spatiotemporal trends in vegetation change (Bhoopathy & Subramanian, 2022; Muhammad Aqeel Ashraf et al., 2011). Aerial images and field observations have been employed to evaluate changes along riparian zones (Taminskas et al., 2020; Wang et al., 2013). This study evaluated the spatiotemporal trends of illegal sand mining effects on mining site extents along the South African coastal zone from the Kei River mouth to the Lubanzi River mouth between 2000 and 2022.

4.2 Methods and materials

The assessment of spatiotemporal trends of illegal sand mining within the study area was analysed using Geographic Information Systems (GIS) techniques, leveraged with digital aerial images to enhance the visualisation of unlawful sand mining sites over the years. The GIS methods deployed were utilised to further improve the accuracy of the study outcomes. To achieve this, digital aerial images were acquired for 2000, 2010 and 2022 from the Chief Directorate: National Geospatial Information (CD: NGI) office, based in Cape Town. To map and analyse the changes in illegal sand mining activities, a 3-kilometre buffer polygon within the study area was created using GIS technique. All aerial photographs were sourced from CDNGI from 2000 to 2022 (Rembold et al., 2000). They were categorised into low-resolution images (23m x 23m), high-resolution (0.5m GSD), and very high-resolution (0.25m GSD). Low-resolution images were for 1926–2008, high-resolution for 2008–2016, and very high-resolution for 2017–present. The study adopted the following methodology to ensure the reliability and accuracy of the outcomes.

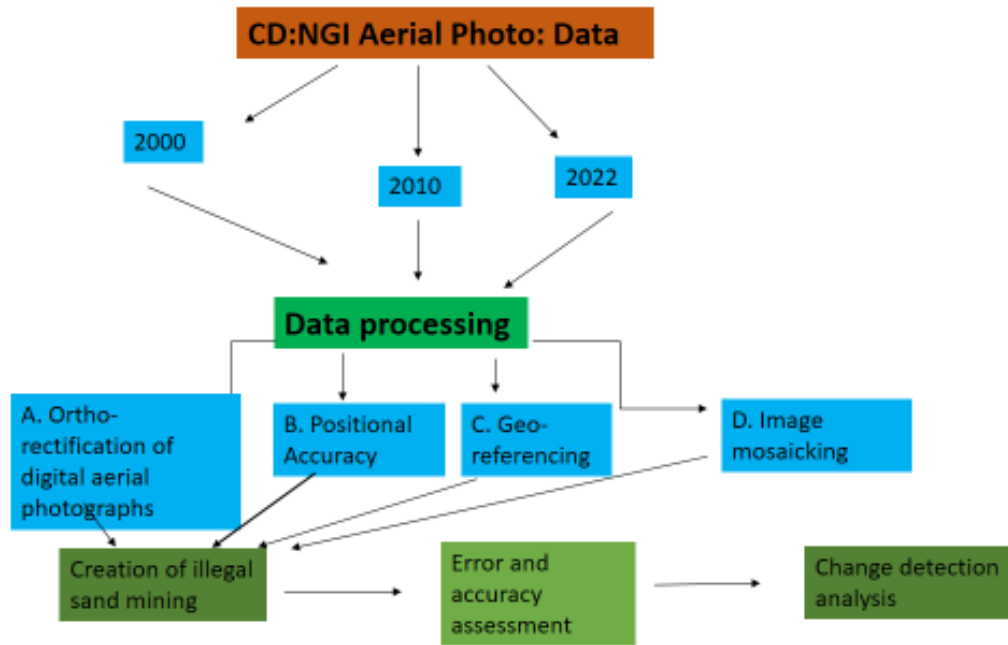


Figure 5: Workflow Diagram



4.2.1 Data Processing

CD pre-processed the digital ortho-photos used in the study: NGI at the time of utilisation for the survey. Data processing of digital aerial photos was achieved using the adopted data processing procedures in accordance with CD: NGI's Standard for the Ortho-Rectification and Mosaicking of Imagery. The procedure entails the following:

Ortho-rectification of digital aerial photographs

The images used in this study were free from all camera distortions. The resampling or interpolation was performed using the bilinear interpolation method. No parts of geo-rectified images were lost or damaged because of data processing. The ortho-rectified images were free from double imaging.

Positional accuracy

All the digitally acquired aerial ortho-photographs were rectified and resampled to a ground sampling distance (GSD) of 0.25 meters. The horizontal positional accuracy of the pixels constituting the ortho-photographs did not exceed 3 meters at the 95% confidence level.

Geo-referencing and projection

The ortho-rectified images were georeferenced on the Hartebeesthoek 94 datum (WGS84 reference ellipsoid) and the Gauss Conform Projection, an approved GIS mapping standard in South Africa. Lastly, the ortho-rectified processes are saved in the GeoTIFF file with Southings and Westings and its accompanying world file (.tfw)

Image Mosaicking

All the distance measurements were expressed in meters. The ground sample distance of the mosaicked imagery was 0.25 meters. The naming of the Geo-tiff file contained the relevant maps reference for the 1: 10 000 National Map Series, the job number and the terms describing the imagery. For example, **3228DA_01_2010_953 RGB_RECT.TIF** was one of the geo-rectified images used in this study.

4.2.2 Creation of Illegal Sand Mining Maps

The maps of illegal sand mining from 2000, 2010 and 2022 were created by overlaying ortho-rectified images with a study area polygon. The grids covering the study area were selected from the grids that cover the whole study area by selection and clipping. The grid map created was overlaid on aerial photographs taken from the multi-temporal periods of 2000, 2010, and 2022. The illegal sand mining was identified using digitisation GIS techniques of the 24 illegal mining sites as identified on the digital aerial photographs. The digital aerial images were acquired for 2000, 2010 and 2022.

4.2.3 Error and Accuracy Assessment of Digitised Illegal Sand Mining Sites

Operational errors in mapping illegal sand mining activities can occur for various reasons, as identified by Dunn et al. (1991). These errors may stem from misinterpreting photos or overlooking packages lying on the ground. Uncertainty about land parcel boundaries can lead to commission errors. Additionally, errors may arise during the digitisation process, where the representation of smooth curves as straight lines can result in discrepancies between the digitised line and the original line on the map (Rivers-Moore, 1997). The final assessment of maps generated using GIS techniques to identify illegal sand mining considered all these potential errors.

On-the-ground observation (OTG) validated the identified locations (Weng, 2002). Coordinates from each site were selected to assess accuracy. After identifying these sites on aerial photos, GPS devices were used to locate them in the field. These coordinates were then used to verify the presence of illegal sand mining sites depicted on maps from 2000, 2010, and 2022. Subsequently, GPS devices and digital cameras were used to confirm the identical positions in the field. The OTG exercise resulted in 24 correct identifications out of 24, indicating confidence in the GIS mapping outcomes.

4.2.4 Change detection analysis

In addition, change detection analysis was performed by comparing the boundary extent of illegal mining sites over the respective years. This was done to determine the growth or decline of the illegal mining sand boundaries between the periods of interest, which were the years 2000, 2010 and 2022. Since the polygon lacked attribute data, the accompanying was manually filled in with information specific to each polygon. The manually populated attributes included filled area coverage, which was used to calculate the total area coverage per site over the years. The calculations were measured in square kilometres. All the datasets used in this study were projected to Hartebeesthoek 94 datum (WGS84 reference ellipsoid) and the Gauss Conform Projection of the same reference system to minimise distortions and get accurate analysis results.



4.3 Results and Discussions

This study unveils a comprehensive analysis of illegal sand mining activities along the Eastern Cape coast, utilising the Chief Directorate: National Geospatial Information (CDNGI) aerial imagery time series from 2000 to 2022. Despite the absence of high-resolution imagery for 1990, this chapter presents a detailed examination of the spatial and temporal trends in suspected mining areas within 3 kilometres of the coastline. The study reveals an alarming escalation in these activities over the observed period by employing remote sensing techniques and GIS tools.

The assessment of spatial and temporal trends of illegal sand mining (i.e., pit size) along the coastal zone from Kei River mouth and Lubanzi River mouth. Twenty-four (24) illegal coastal

sand mining sites (pits) were identified between the Kei River mouth and Lubanzi River mouth; only sites within 3 kilometres from the high-water mark from the sea were identified. All the sites were active during the data collection except for one inactive site, and they are represented in the map below (figure 6).

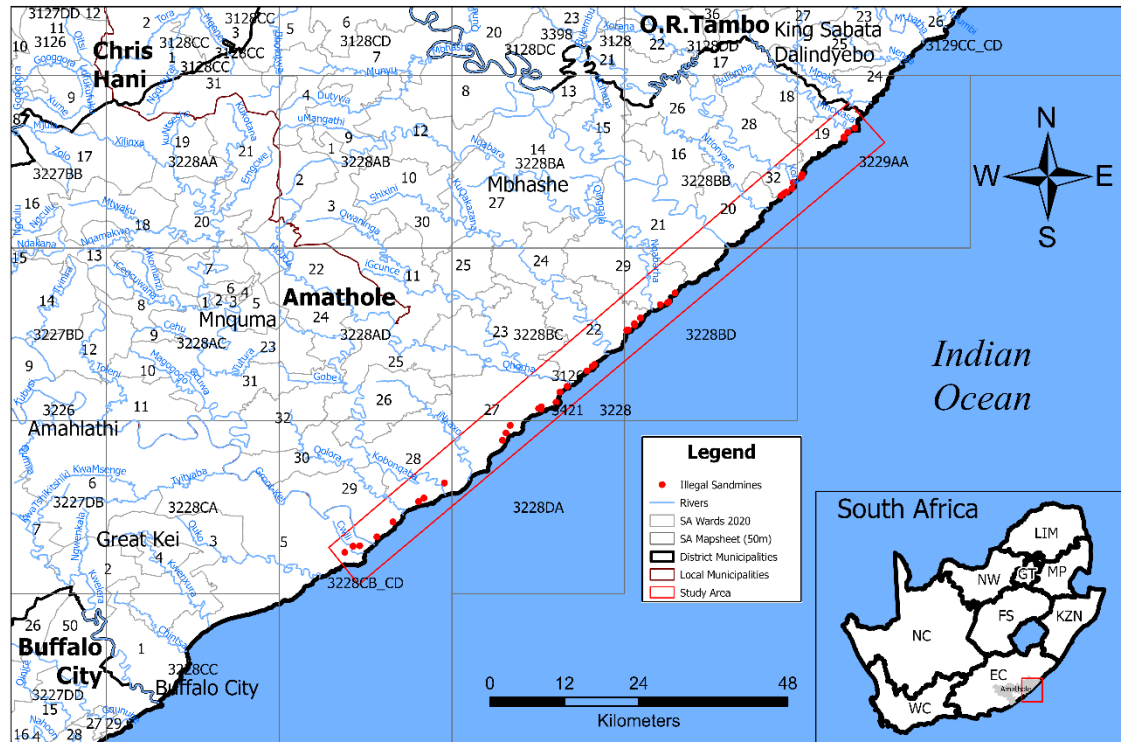


Figure 6: Locations of the 24 illegal mining sites from Kei River mouth to Lubanzi River

After digitising all the illegal sand mining sites over the years, the extent of illegal sand mining in 2000 was **338905.8 km²**, in 2010 was **760998.6 km²** and in 2022 was **1332826.0 km²**. Therefore, results show that unlawful sand mining occurred at the Mbolompo Point area, with more than 220000 km² in the year 2022, followed by the Kwaqoqo area, with more than 160000 km², and the third place was the Ngadla River estuary, with 134400 km² (Table 4). The results also show that the Mbolompo point area was the first big pit in 2010, with more than 160000 km², followed by Kwaqoqo with 132100 km² and Ngadla River estuary with 81300 km² (Table 4). The extent of illegal sand mining in 2000 was less than 100000 km² in all 24 sites; most unlawful sand mining occurred at the Kei mouth area with 67826,54 km², followed by Kwaqoqo with 55800 km².

Table 4: Illegal sand mining sites on the coastal area from Kei to Lubanzi River mouth

#	Place Names / Rivers Name	Nearby River	GPS Coordinates		Polygon Area Measurements in (km ²)		
	Names		X	Y	2000	2010	2022
1	Kei Mouth 1	Cwili	28,35757	-32,6812	1560.2	4873.28	6101.3
2	Kei Mouth 2	Cwili	28,34558	-32,6901	12057.67	1120.91	13013.73
3	Kei Mouth 3	Groot-Kei	28,39184	-32,6678	67826.54	53041.98	73645.99
4	Qoloha	Qolora	28,41395	-32,6463	4464.97	12866.94	42890.6
5	Ncizela River Sandmines	Qolora	28,45146	-32,6186	12239.62	63025.72	106518.37
6	Ncizela2	Kobonqaba	28,45988	-32,6117	31614.54	47179.0	65741.5
7	Kwagcaleka	Kobonqaba & Inxaxo	28,50384	-32,5983	3383.14	7854.72	28713.08
8	Ncata	Inxaxo	28,57428	-32,527	2477.06	12772.67	48853.27
9	Ncata2	Inxaxo	28,57851	-32,517	2134.13	8816.67	22602.51
10	Ncata3	Inxaxo	28,58386	-31,4935	28004.98	32587.36	42975.12
11	KwaXambeni	Inxaxo	28,62681	-32,4814	0	6099.61	48015.77
12	kuloJingqi	Qhorha	28,69678	-32,4273	8920.08	64264.02	102720.2
13	Ngadla River Astuary	Shixini	28,70453	-32,4203	37041.4	81325.67	134416.64
14	Tenza	Shixini	28,75508	-32,3689	2503.27	4357.0	16987.15
15	Kwaqoqo	Shixini	28,76603	-32,36	55884.89	132159.22	168909.72
16	Kunocekedwa	Nqabarha	28,7729	-32,3509	3277.98	15806.17	82859.01
17	Plaatjie_Nqabala	Nqabarha	28,80191	-32,3318	5990.9	5277.84	17885.36
18	Ntubeni	Nqabarha	28,81397	-32,3276	10653.59	5618.06	9636.48
19	Dwesa Point	Nqabarha	28,823	-32,3146	8367.48	22890.01	28468.62
20	Nkanya River	Xora	28,97666	-32,1742	16752.12	4570.2	21652.56
21	Nkanya2	Xora	28,98505	-32,169	119.11	7449.54	12210.57
22	Nkanya3	Xora	28,992	-32,1636	16752.12	0	0
23	Xhora River	Xora	28,994	-32,155	3771,85	4782.01	15914.64
24	Mbolompo point	Mncwasa	29,08387	-32,0768	3108.17	162260.03	222094.25
	Total Area				338905.8	760998.6	1332826.0

4.3.1 Field Data Collection

A total of 24 sites were visited; Global Positioning System (GPS) Garmin machine was used to capture the waypoints, and digital cameras were used to capture the physical damage caused by illegal sand mining (Figure 7). Moreover, the vehicle mileage measured the distance between the village and illegal mining sites.



Figure 7: Physical damage caused by illegal sand mining, and open pits used for dumping and livestock fed on the dumping waste (Photographs were taken by M. Dandala & M. Jakavula)

4.3.2 Illegal mining sites 2000, 2010, and 2022

In the study area, none of the sites possess a valid license as required by the Mineral and Petroleum Resources Development Act No. of 2008, rendering all the sites illegal. Consequently, all data presented below pertain to unlawful sand mines under current legislation. Figure 8 illustrates three illegal sand mining sites near the Kei River mouth, marking the beginning of the study area. The site one, represented as Kei Mouth 1 in the table,

exhibits a change increase of 3313 km² between 2000 and 2010, while the difference between 2010 and 2022 is 1282.02 km². The site two, denoted as Kei Mouth 2 in the table, depicts a difference change of 10936.76 km² between 2000 and 2010, followed by a change increase of 11792.82 km² between 2010 and 2022. The site three corresponds to Kei Mouth 3 in the table, showing a change of difference 14784.56 km² between 2000 and 2010, followed by a change increase of 20604.01 km² between 2010 and 2022. Several factors may have contributed to the fluctuation in sand mining activity at Kei Mouth. The proximity of Kei Mouth to hotels and cottages whose owners are members of the Wild Coast Association could play a role. These individuals are likely well-informed about the laws and regulations governing sand mining and may maintain strong relationships with authorities. As a result, they may act as vigilant whistleblowers when illegal mining activities are suspected.

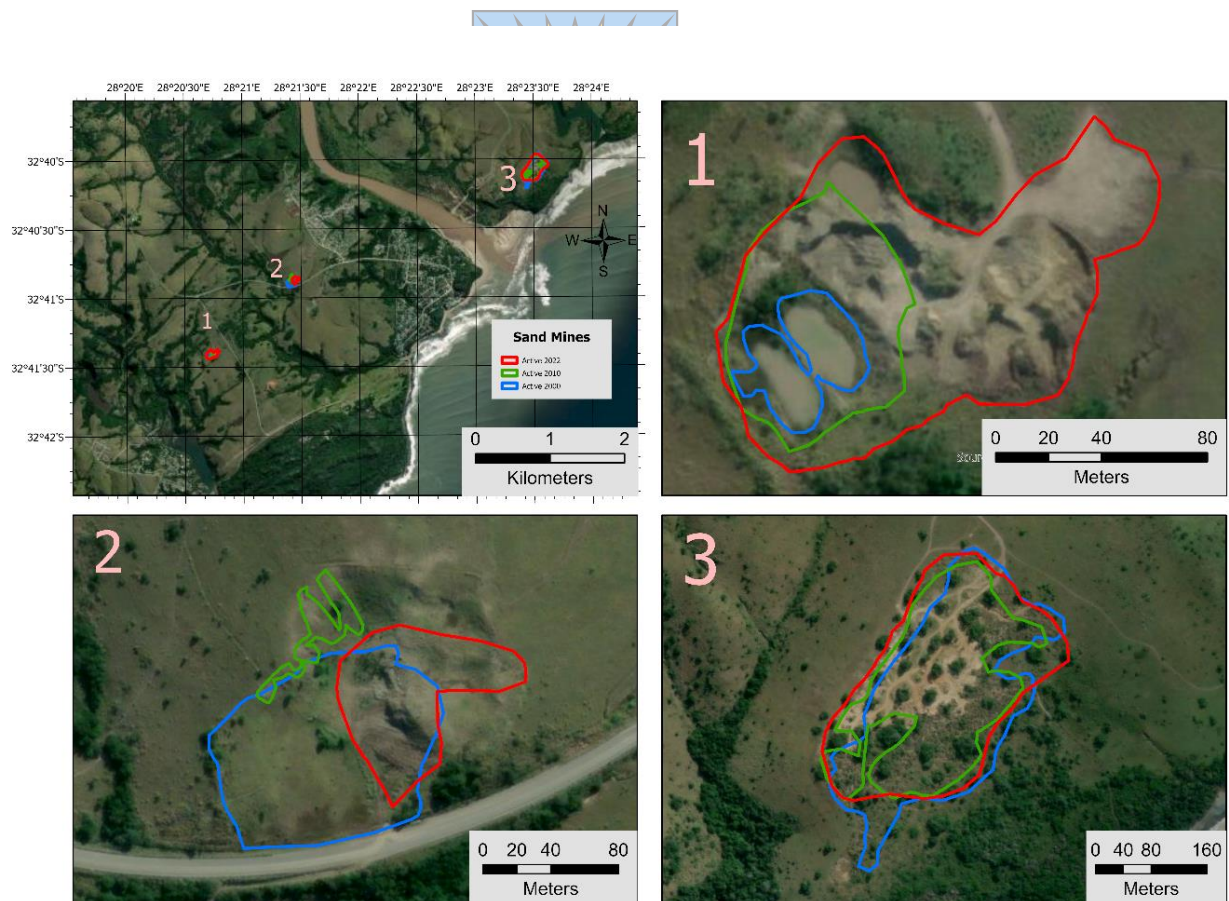


Figure 8: Illegal sand mines near Kei Mouth/ Kei River Mouth, labelled as 1,2 and 3. Blue represents 2000, Green is 2010, and Red is 2022.

Figure 9 depicts three illegal sand mining sites near the Qolora and Kobonqaba Rivers. The site four, Qolora, in the table, indicates a change increase of 8401.97 km² between 2000 and 2010. Subsequently, between 2010 and 2022, the same site demonstrates a difference of 30023.66 km². The site five, labelled as Ncizela River sand mines in the table, exhibits a difference of 50786.1 km² between 2000 and 2010. Furthermore, between 2010 and 2022, a change increase of 43492.65 km² was observed. The site six corresponds to Ncizela 2 in the table, showing a difference of 15564.56 km² between 2000 and 2010. Similarly, between 2010 and 2022, the site demonstrates a change increase of 8562.5 km².

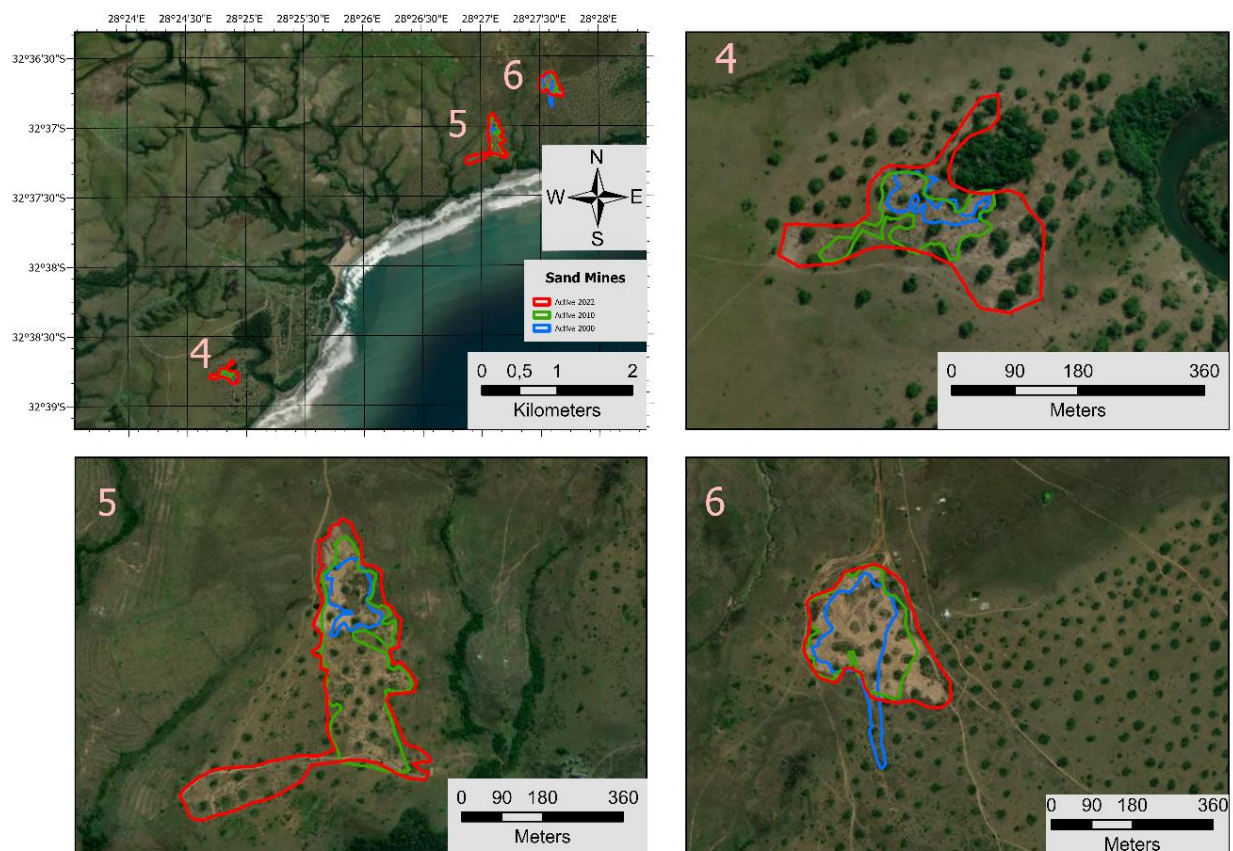


Figure 9: Illegal sand mining sites Qolorha, Ncizela River and Ncizela 2, respectively.

Figure 10 represents only one illegal sand mining site that is close to or near Kobonqaba and Inxaxo. The site seven represents Kwagcaleka in the table; the site shows a change increase of 4471.58 km² between 2000 and 2010, while it shows a difference of 20858.36 km² between 2010 and 2022.

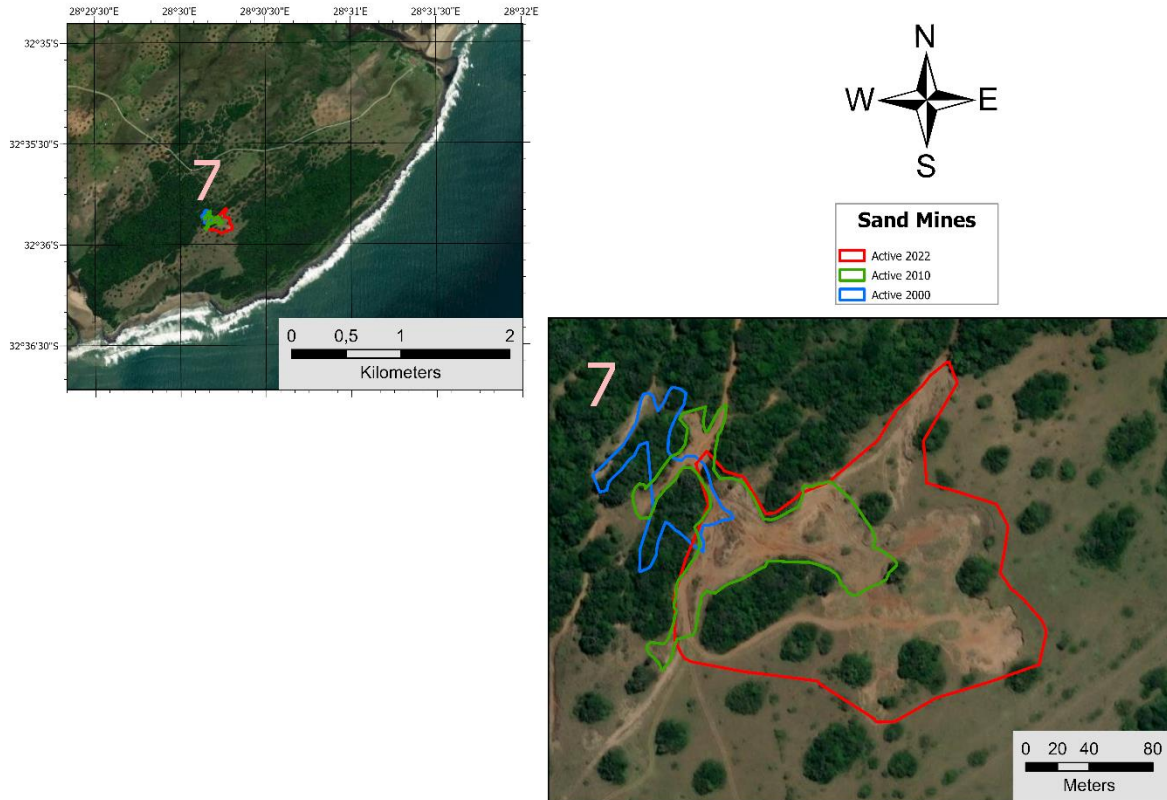


Figure 10: Illegal sand mining site, Kwagcaleka



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Figure 11 depicts four illegal sand mining sites located near the Inxaxo River. Each site is labelled according to a numerical identifier in the table. Here's a breakdown of the data presented:

1. Site eight corresponds to Ncata 1 in the table. It indicates a change increase of 10295.61 km² between 2000 and 2010 and a further change increase of 36.080.6 km² between 2010 and 2022.
2. Site nine corresponds to Ncata 2 in the table. It shows a difference of 6682.54 km² between 2000 and 2010, followed by change increase of 13.785.84 km² between 2010 and 2022.
3. Site ten represents Ncata 3 in the table. It demonstrates a difference of 4582.46 km² between 2000 and 2010 and a change increase of 10387.76 km² between 2010 and 2022.

4. Site eleven represents KwaXambeni in the table. It shows a difference of 6.099.61 km² between 2000 and 2010, followed by a significant increase change of 41.916.16 km² between 2010 and 2022.

These figures indicate the changes in the illegal sand mining sites over time, with considerable increases observed in most cases, highlighting the magnitude of the issue.

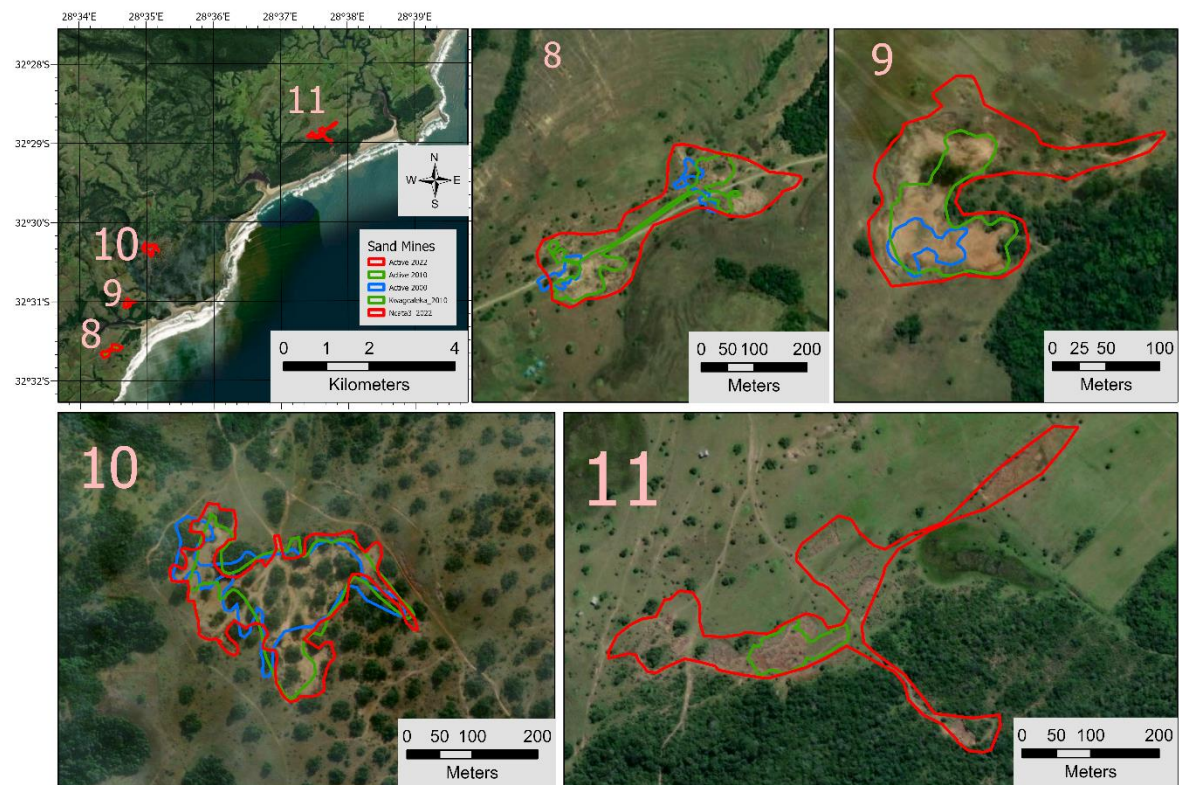


Figure 11: Illegal sand mining sites, Ncatha 1, Ncatha 2, Ncatha 3 and KwaXambeni respectively

Figure 12 represents two illegal sand mining sites close to the Qhora River. The site 12 represents Kulojingqi in the table; the site shows an increase change of 55343.94 km² between 2000 and 2010, while it shows a difference of 38458.18 km² between 2010 and 2022. The site 13 represents the Ngadla River estuary in the table; the site shows a difference of 44284.27 km² between 2000 and 2010, while 2010 and 2022 show a difference increase of 53090.97 km².

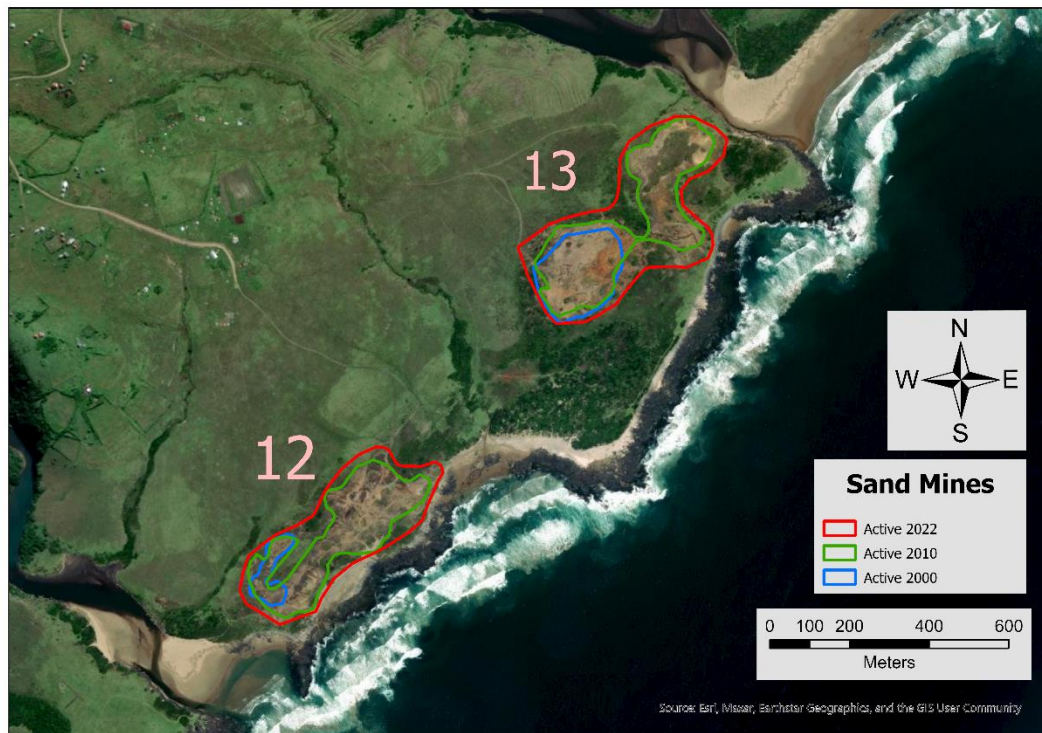


Figure 12: Illegal mining sites at Kulojingqi and Ngadla river



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Figure 13 illustrates three illegal sand mining sites situated near the Shixini River. Each site is identified by a numerical label corresponding to the table. Here's a breakdown of the data provided:

1. The site 14 represents Tenza in the table. It indicates an increase change of 1853.73 km² between 2000 and 2010, followed by a substantial rise of 12630.15 km² between 2010 and 2022.
2. The site 15 represents Kwaqoqo in the table. It demonstrates a difference of 76274.31 km² between 2000 and 2010, with a subsequent increase change of 36750.52 km² between 2010 and 2022.
3. The site 16 represents Kunocekedwa in the table. It shows a difference of 12528.19 km² between 2000 and 2010, followed by a significant increase change of 67052.84 km² between 2010 and 2022.

These figures provide insight into the changes in the area of the illegal sand mining sites over time, highlighting considerable increases in most cases.

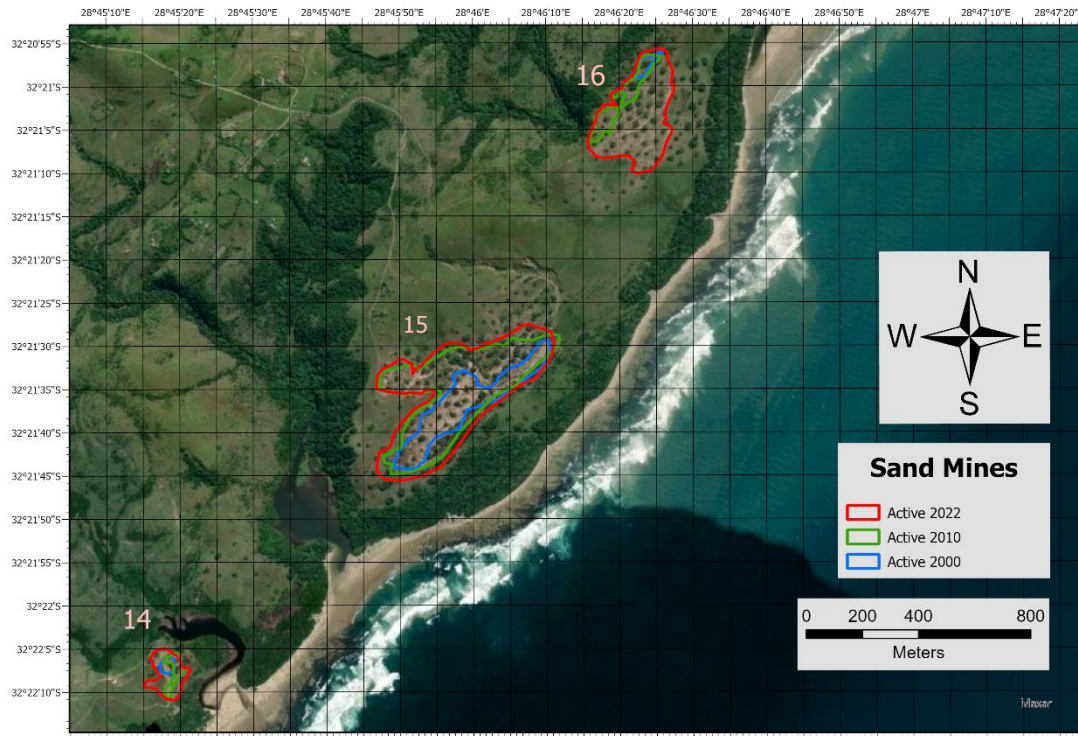


Figure 13: Illegal mining sites at Tenza, Kwaqoqo and Kunocekedwa, respectively.

Figure 14 depicts three illegal sand mining sites located near the Nqabarha River. Each site is labelled with a numerical identifier corresponding to the table. Here's a breakdown of the data provided:

1. The site 17 represents Plaatjie Nqabarha in the table. It shows a difference 713.06 km² between 2000 and 2010, followed by an increase change of 12607.52 km² between 2010 and 2022.
2. The site 18 represents Ntubeni in the table. It demonstrates a difference 5035.53 km² between 2000 and 2010, with an increase change of 4018.42 km² between 2010 and 2022.

3. The site 19 represents Dwesa's point in the table. It shows a difference of 14522.53 km² between 2000 and 2010, followed by an increase change of 5578.61 km² between 2010 and 2022.

These figures provide insight into the changes in the area of the illegal sand mining sites near the Nqabarha River over time, highlighting both difference and increases in the site area.

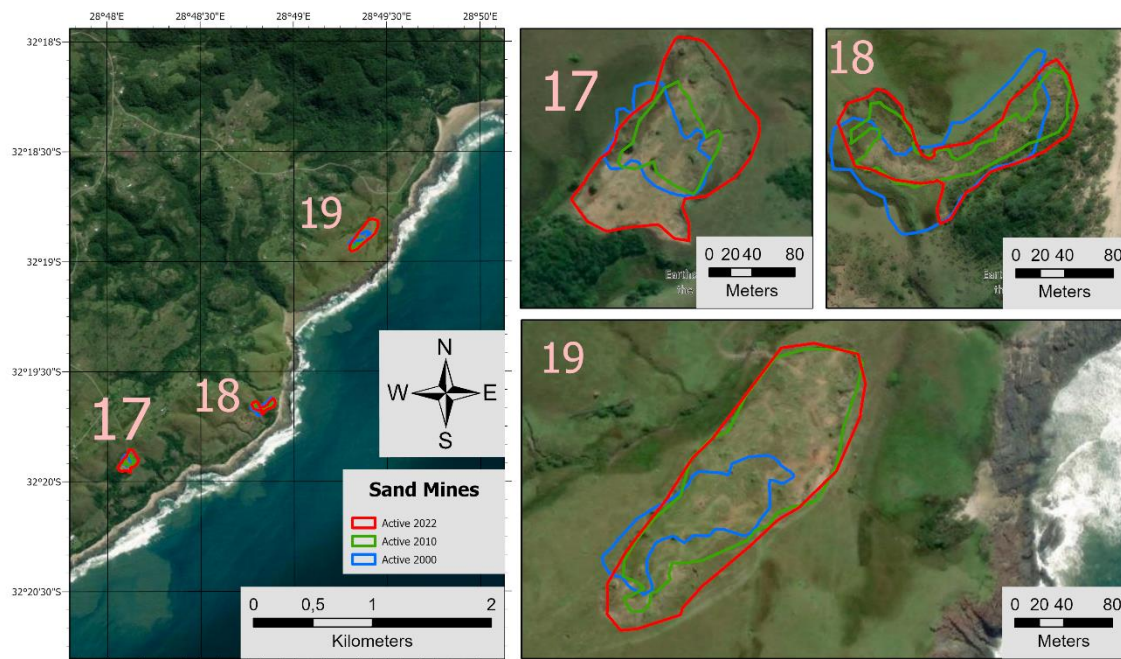


Figure 14: Illegal sand mining at Plaatjie Nqabarha, Ntubeni and Dwesa point, respectively.

Figure 15 illustrates four illegal sand mining sites located close to or near the Xhorha River. Each site is identified by a numerical label corresponding to the table. Here's a breakdown of the data provided:

1. The site 20 represents the Nkanya River in the table. It shows a difference of 12281.92 km² between 2000 and 2010, followed by an increase change of 17.082.36 km² between 2010 and 2022.

2. The site 21 represents Nkanya 2 in the table. It demonstrates a significant increase change of 7330.43 km² between 2000 and 2010, followed by a difference of 4761.04 km² between 2010 and 2022.
3. The site 22 represents Nkanya 3 in the table. It shows a difference of 16.752 km² between 2000 and 2010 and no change (0.0 km²) between 2010 and 2022.
4. The site 23 represents the Xhora River in the table. It indicates a difference of 1010.17 km² between 2000 and 2010, followed by a substantial increase change of 11132.62 km² between 2010 and 2022.

These figures provide insights into the changes in the area of the illegal sand mining sites near the Xhorha River over time, showing variations in site area, including both increases and difference.

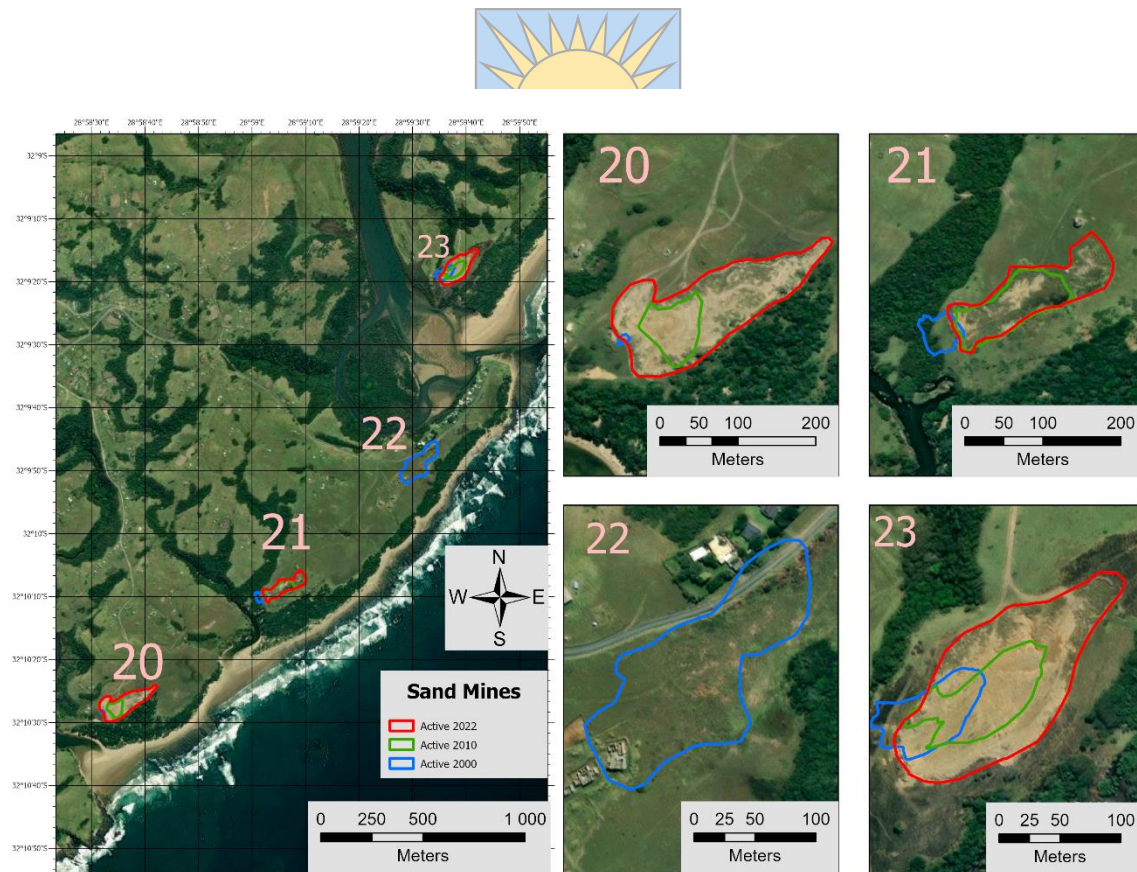


Figure 15: Illegal sand mining at Nkanya river, Nkanya 2, Nkanya 3 and Xhora river, respectively.

Figure 16 represents one illegal sand mining site that is close to or near the Mncwasa River. The site 24 represents the Mbolompo point in the table; the site shows a considerable difference of 159151.86 km² between 2000 and 2010, while it shows a difference of 59834.22 km² between 2010 and 2022.

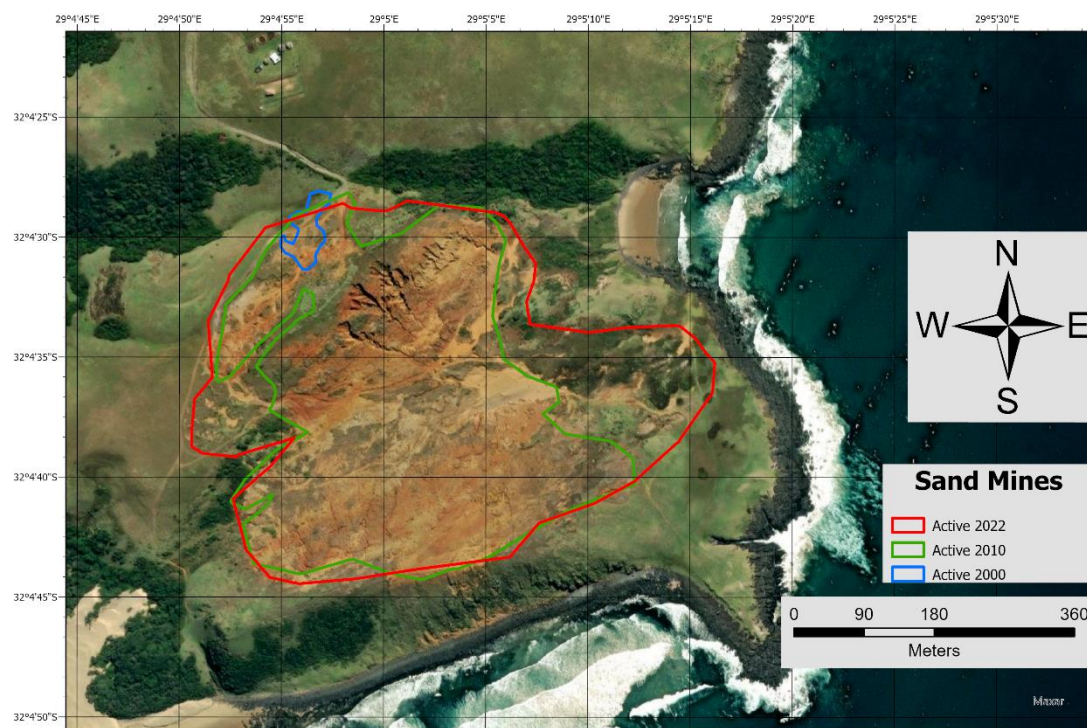


Figure 16: Illegal sand mining at Mbolompo point.

4.3.3 Change detection analysis

The change detection analysis covers 2000 to 2010 and 2010 to 2022. The total change was **422092.82 km²** from 2000 to 2010, and the total change was 571827.81 km² from 2010 to 2022. The total difference between the past 22 years is close to 149734 km² it is evident that illegal sand mining has increased over the last two decades.

Table 5 Change detection analysis 2000-2022.

Site Name	Change Detection (2000-2010) in km ²	Change Detection (2010-2022) in km ²
Dwesa Point	14522.53	5578.61
Kei Mouth 1	3313.08	1228.02
Kei Mouth 2	-10936.76	11892.82
Kei Mouth 3	-14784.56	20604.01
kuloJingqi	55343.94	38456.18
Kunocekedwa	12528.19	67052.84
Kwagcaleka	4471.58	20858.36
Kwaqogo	76274.33	36750.5
KwaXambeni	6099.61	41916.16
Mbolompo point	159151.86	59834.22
Ncata1	10295.61	36080.6
Ncata2	6682.54	13785.84
Ncata3	4582.38	10387.76
Ncizela River Sandmines	50786.1	43492.65
Ncizela2	15564.46	18562.5
Ngadla River Astuary	44284.27	53090.97
Nkanya River	12181.92	17082.36
Nkanya2	7330.43	4761.03
Nkanya3	-16752.12	0
Ntubeni	-5035.53	4018.42
Plaatjie_Nqabala	-713.06	12607.52
Qoloha	8401.97	30023.66
Tenza	1853.73	12630.15
Xhora River	1010.16	11132.63
Grand Total	422092.82	571827.81

The graphical comparison in Figure 17 illustrates the change in detecting illegal sand mining activities from 2000 to 2010 and 2010 to 2022. The analysis indicates that the most significant changes occurred between 2000 and 2010. Additionally, the study reveals that one of the sites was inactive or ceased operations between 2000 and 2010. This cessation of activity is attributed to sand depletion and erosion of roads, leading to restricted access to the site.

rates in South Africa, sand mining provides employment opportunities to families involved in truck ownership, truck driving, and loading.

Rapid Population Growth

The demand for sand is driven by rapid population growth, particularly in urban areas where construction material demands have increased significantly over the past two decades. This growth has led to a surge in infrastructure construction, such as roads and buildings, all requiring sand. For example, sand was likely used to construct RDP houses in the study area. However, given that there are no legal sand mining sites in the study area as required by legislation, it is assumed that the sand used may have been obtained illegally. Several studies have linked sand mining with socioeconomic opportunities and challenges faced by host communities. These studies suggest that sand mining can improve socioeconomic conditions by providing residents with additional income and employment opportunities (Asabonga et al., 2017; Masalu, 2002; Rais et al., 2019).

4.5 Conclusion

This research aimed to establish spatio-temporal change patterns that occurred in the study area using GIS and aerial photograph images. It aimed to investigate the capability of GIS to analyse trends using maps generated from aerial photographs effectively. It was assumed from the outset that utilising aerial photographs and GIS would provide better insight and understanding of the pit sizes or illegal mining sites over the years. The data from images obtained from NGI were processed through ortho rectification, positional accuracy, georeferencing, and image mosaicking to create illegal sand mining polygons. The information generated in this project can assist in answering the following questions: where are the unlawful mining hotspots? Furthermore, law enforcement agencies can use the information generated to minimise illegal sand mining.

The findings of the study reveal that in 2022, the majority of illegal sand mining occurred in three primary areas: the Mbolompo point region, spanning over 222.094 km²; the Kwaqoqo area, covering more than 168.909 km²; and the Ngadla River Estuary, comprising 134.416 km². The investigation further indicates that the Mbolompo point area, exceeding 162.260 km², was the most significant pit identified in 2010. Following this, Kwaqoqo, covering 132.159 km²,

and the Ngadla River Estuary, spanning 8.325 km², were identified as critical areas of illegal sand mining. Overall, the study identified 24 locations with areas of illegal sand mining exceeding 100.000 km² around 2000. The study suggests that the period from 2000 to 2010 had the most significant impact on illegal sand mining activities, as land cover protection measures were less stringent along coastal zones, allowing for extensive unlawful sand excavation. Notably, the Kei Mouth area, covering 67.826 km², and Kwaqoqo, spanning 55884.89 km², were the primary sites of illegal sand mining during this period.

The social and economic effects of the rising demand for sand cannot be overstated. Private property owners continue to benefit exclusively from coastal resources through their possessions, while the general public remains restricted. This has hampered the effectiveness of the legislative framework governing coastal zones and its violation by illegal sand mining operations. However, this has become a universal problem requiring immediate attention through appropriate legislation and innovative methods, including the networked governance partnership through the conglomerate action to re-evaluate illegal sand mining operations. This strategy would safeguard ecologically sustainable development and use of natural resources, promote conservation, and prevent pollution and ecological degradation while encouraging legitimate economic and social growth. The current study contributes to a better understanding of linking the information gap in the literature through the conglomerate approach to decision-making and multi-level solutions of networked governance in solving illegal sand mining activities. The use of Geographic Information System (GIS) and Remote Sensing (RS) technology has been scantily quantified to detect illegal sand mining and the associated direct and indirect environmental effects in South Africa. The GIS and RS database can provide a reliable platform to identify hotspot areas' extent and impacts of illegal sand mining using satellite imagery-based analysis for inspection processes in national and provincial priority areas of South Africa. The importance of illegal mining is not equivalent to the sand volume that has been mined; there is a need to investigate how many quantities have been taken and the value of those quantities so that we understand the contribution of sand to Gross Domestic Product (GDP).

Chapter 5: To assessment the impact of illegal sand mining activities on the landscape dynamics (i.e., land use change and vegetation cover change) in the study area.

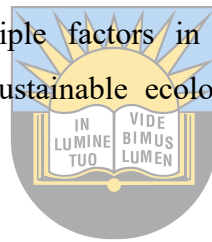
5.1. Introduction

Due to irreversible environmental deterioration caused by illegal sand mining, the physical and environmental effects of sand mining have evolved into crises that often result in informal, unsustainable changes in land use dynamics (Asabonga et al., 2017; Smaliychuk et al., 2021). An impressive example of extensive and unsustainable sand and land use practices leading to widespread environmental degradation due to both natural and anthropogenic consequences is illegal sand mining extraction (Clark & Johnston, 2017; Smaliychuk et al., 2021). Eliminating native flora and soil in coastal-sensitive regions, inland biological corridors, riverbanks, and estuary ecosystems poses severe dangers to ecosystem-sensitive places (Thomas, 2019).

Rapid urbanisation is one of the main drivers of sand demand globally (Gavriletea, 2017) and is responsible for the unsustainable removal of sand from numerous illegal inland sand mining pits located throughout the nation. Most developing countries face the issue of illegal and excessive sand mining with strict measures to regulate these practices under government policies, yet the legislative frameworks have not been effective (Bhatawdekar et al., 2023; Debrah et al., 2014). Weaker government policies for sand extraction have led to illegal mining in rural areas, reducing ecological land productivity. Mining is one of the land-use processes with adverse environmental effects and substantial land footprints that frequently cause land degradation (Sonter et al., 2014). To address issues related to mining exploitation, for instance, the United Nations Sustainable Development Goal 15 is defined as achieving the land degradation neutrality target (UN, 2015). One of the key factors influencing the effect of natural processes that directly contribute to land degradation is land use change (Shao et al., 2020).

Several studies have assessed the long-term spatial and temporal variability of land use and dynamics of illegal sand mining activities in response to the vegetation change trend of unlawful sand mining activities along the coastal zone (Dar et al., 2023; Duan et al., 2019; Gruel & Latrubesse, 2021; Sulla-Menashe et al., 2016; Xu et al., 2021). Only a few studies have mapped the land use dynamics of illegal sand mining activities with several vegetation indices and climate variables, particularly at the local level, including in South Africa (Gondo

et al., 2019; Green, 2012; Mbolambi, 2016; Rudke et al., 2020). However, their findings showed that between 2014 and 2016, there was a significant conversion of agricultural and forest land to bare soil, which was attributable to the upsurge in illegal sand mining in the area. Smaliychuk et al. (2021) examined most of Polissia's administrative districts. They found that from the late Soviet era through 2014, there was a steady drop in areas lacking vegetative cover, a sign of degraded land. Their research revealed that between 2014 and 2016, a considerable amount of forest and agricultural land in the region turned to bare soil because of the upsurge in illegal sand mining. Singh et al. (2015) deployed a novel system to monitor illegal sand mining using a novel vehicle identification technique that identified the quantity of sand maximum threshold value particular to the identified vehicle with an average accuracy rate of 94.9%. Like this, artisanal and small-scale mining in Madre de Dios, Brazil, was mapped using Landsat data with a 96% overall area-weighted accuracy, which revealed a significant amount of illegal sand mining activity (65%) (Elmes et al, 2014; Singh et al., 2015). Findings from previous studies revealed that the implications associated with illegal sand mining are not only environmental but caused by multiple factors in the long term, with socioeconomic consequences that may lead to unsustainable ecological imbalance (Cho & Kao, 2022; Upadhyay, 2019).

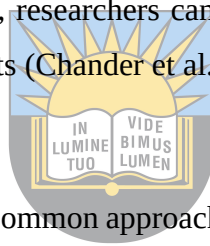


The combination of GIS and Remote Sensing applications provides a cost-effective evaluation over extensive areas at different spatial and temporal scales in detecting, monitoring, and assessing land use and dynamics of illegal sand mining activities changes (Chamling & Bera, 2020; Murguía, 2015). Assessing the spots of degraded lands is necessary to guide enforcement and rehabilitation for effective decision-making processes along the coastal zone. The detection and environmental monitoring of sand resource extraction locations around the world, including regions of illegal sand mining operations, are frequently done using satellite-derived data (Gallwey et al., 2020; Lei et al., 2019; Mahrad et al., 2020). To this end, the study utilised multi-source satellite imagery to identify this research gap and monitor land-use change detection of illegal sand mining activities. Hence, this study mapped land-use change dynamics of illegal sand mining activities along the Amathole District Wild Coastal Zone of the Eastern Cape Province, South Africa, from 2000 to 2022. The deductions of this study will provide government and environmental stakeholders with predictive mapping techniques to identify the coastal ecological changes and the potential hotspots for illegal sand mining to guide micromanaging decisions.

5.2. Materials And Methods

5.2.1 Remote Sensing Data Methodology

The detection and long-term monitoring of Land Use Land Cover Change (LULCC) can be accomplished through various methods. Historically, researchers have mapped LULCC across small areas using field data and aerial photos. However, as the study area expands, these procedures become more expensive and time-consuming (Fonji & Taff, 2014). Recently, high spatial resolution imageries like IKONOS, QuickBird, WorldView, and RapidEye have been increasingly utilised for large-scale LULC mapping due to their ability to provide accurate terrain characteristics and information about the size and shape of objects (Hu et al., 2013). In this study, Landsat imagery was employed as high spatial resolution imageries have limited spatial coverage and high economic costs, making them more suitable for LULC mapping in smaller areas (Hu et al., 2013). Another advantage of using Landsat observations is the representation of significant and ongoing recordings of the earth's surface (USGS, 2014). With free access to the full Landsat record, researchers can quickly identify and track changes in both natural and artificial environments (Chander et al., 2009).



This study utilised Landsat images, a common approach to remotely sensed data (RS) analysis, to examine the condition of the landscape and its changing patterns in developing countries. The supervised Maximum Likelihood Classification (MLC) approach was employed to classify digital number (DN) values into various classes in the research area. This algorithm performs optimally when each designated class has a Gaussian distribution (Tateishi et al., 2004). Landsat satellite images from 2000, 2010, and 2022 were utilised, each differing in sensor and spectral range. Specifically, Landsat 5 Thematic Mapper (TM) was used for the year 2000, Landsat 7 Enhanced Thematic Mapper (ETM) + for 2010, Landsat 5 TM for 2006, Landsat 5 TM for 2011, and Landsat 8 OLI/TIRS for 2014. Post Classification Change Detection techniques, including Land Use Change Matrix, Image Differencing, and Changes in LULC, were employed to quantify the extent of illegal sand mining in the area over the specified year intervals. The overall process is outlined in a flow chart depicted in Figure 18.

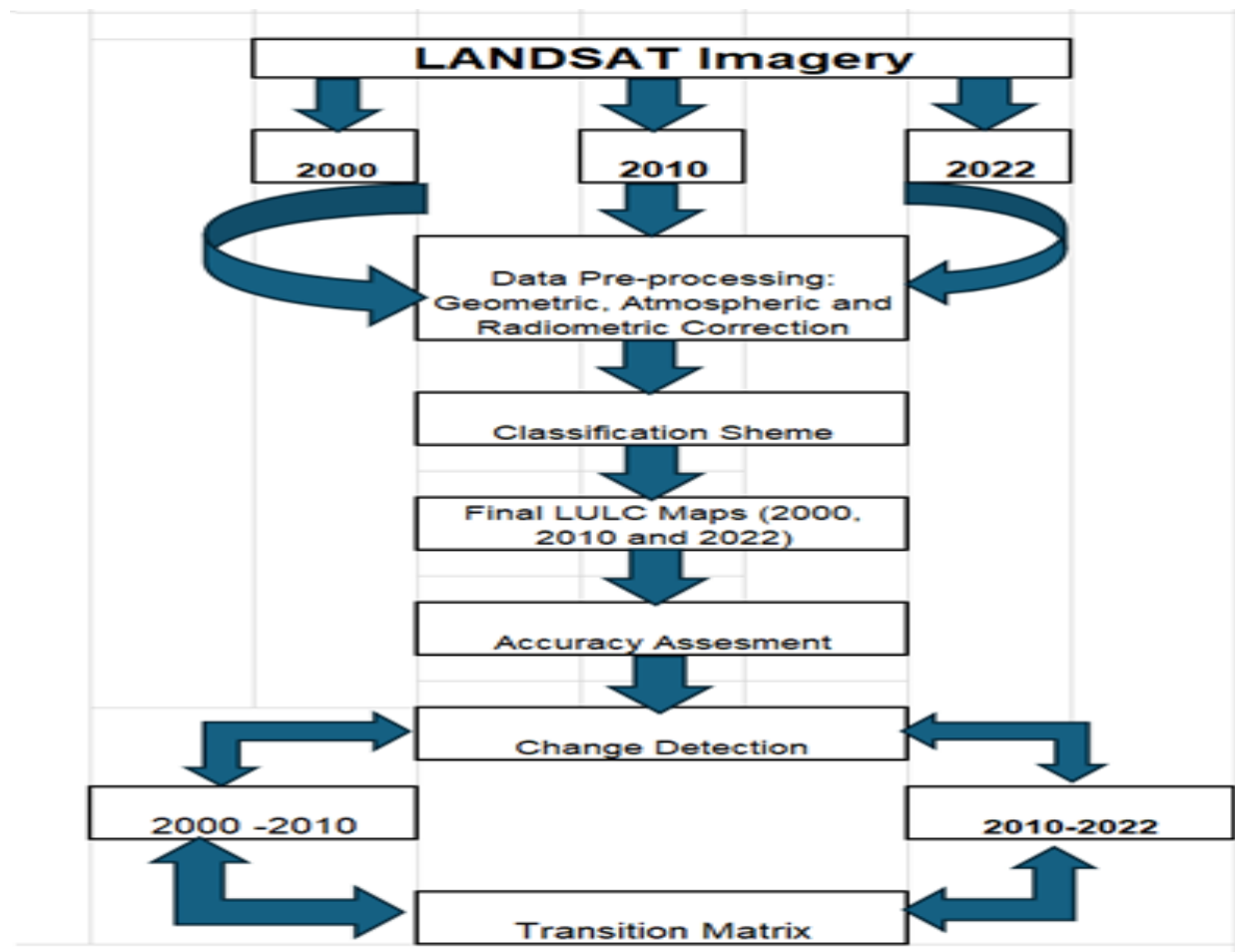


Figure 18: Data preparation and pre-processing flow chart.

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5.2.2 Data Acquisition

Three 30 m-resolution Landsat images were downloaded from the United States Geological Survey (USGS) website (<http://earthexplorer.usgs.gov/>) during the dry season with zero cloud cover. The dry season was chosen to best detect the spectral signatures of various land-cover types, particularly bare areas. The first image was Landsat 5 Thematic Mapper (TM) for 2000, obtained on July 18, 2000. The second image was Landsat 7 Enhanced Thematic Mapper (ETM) + for 2010, received on June 5, 2010. The third image was Landsat-8 OLI sensors + for the year 2022, received on July 7, 2022 (Hussain et al., 2022; Kumar et al., 2021). These images were on path 169, rows 082 and 083, with a spatial resolution of 30x30 meters. To minimise distortions and ensure accurate analysis results, all datasets used in this study were projected to the same reference system, Universal Transverse Mercator (UTM) WGS 1984 Zone 35S.

Pre-processing of Landsat images was conducted before their use in the study. High levels of geometric precision, radiometric, and atmospheric correctness are necessary for mapping operations for both historical and contemporary times (Lu et al., 2004). Image enhancement, georectification, atmospheric correction, and radiometric correction were performed using ArcGIS Pro version 3.2 software. Additionally, image mosaicking operations combined the different bands of Landsat satellite images. The images were rectified to Universal Transverse Mercator (UTM) projection, World Geodetic System (WGS) 1984, and Zone 36 South for accurate analysis. Image classification involves categorising pixels of an image into a smaller number of individual land cover and land use classes based on reflectance values (Campbell et al., 2005; Jensen, 2009). A classification scheme was developed based on prior knowledge of the study area, including classes such as water bodies, built-up areas, bare soil, forest, and other vegetation (Table 6). Supervised classification using the Maximum Likelihood Classification (MLC) was performed after generating spectral signatures of various classes. Training and validation samples were obtained to develop an efficient classifier. Given the variable nature of the study area, multiple sets of 25 ground truth or reference data were used for training and evaluating the accuracy of the map. There were 110 sample points that were used for classification and a total of 110 accuracy assessment points were used to validate land cover classes.

Table 6: The land cover and land use classification scheme and attributes

Code	LULC Categories	Description
1	Water bodies	Streams, rivers, ponds, dams, and reservoirs
2	Built-up areas	Industrial, residential, factories and commercial structures.
3	Bare soil	Areas of land within and around the forest that have no vegetation cover, including mining surfaces
4	Forest	Reserved and protected forest. This type of land has a tree-crown area density of up to 10% or more and is stocked with trees that produce timber and several wood products.
5	Other vegetation	Land that is used to produce fibre and food primarily. This type of land also includes the ones with commercial and horticultural crops.

Source: (Anderson, 1976)

(c) LULC Maps

LULC maps for 2000, 2010 and 2022 were generated after editing and finalisation. The areas of the classes in square meters were extracted and used for the statistical analysis. The area in square meters and the percentage change for each year (2000, 2010 and 2022) were measured against each land use/land cover type developed. Percentage change to determine the change trend was calculated using the relation $\text{Percentage change} = (\text{Observed change} / \text{Sum of change}) \times 100$. A change in the area was indicated as either positive or negative.

(d) Accuracy Assessment of Remotely Sensed Images

The inclusion of historical images or images collected years ago in the analysis of Land Use and Land Cover Change (LULCC) is often hindered by the unavailability of ground reference data (Witmer, 2008). Additionally, the classification of these images may contain errors due to spectral confusion, noise, and limitations of classification algorithms (Liu & Cai, 2012). Therefore, it is crucial to assess the quality of each classified Landsat image for post-classification analysis, which provides meaningful insights (Lu et al., 2004). The primary objective of this assessment was to quantitatively determine how effectively pixels were grouped into the appropriate feature classes within the study area. To evaluate the accuracy of the classified images, a confusion matrix was constructed using ground truth regions of interest (ROIs), with twenty-five (25) ground truth samples selected using a stratified random sample approach. High-resolution Google Earth Pro satellite images for 2000, 2010, and 2022 were utilised for the assessment.

The confusion matrix enabled the computation of the kappa statistic, overall accuracy, producer accuracy, and user accuracy (Adam et al., 2014; Cohen, 1960). Overall accuracy values and Kappa Statistics were generated for the classified images of each respective year. Overall accuracy represents the probability that a randomly selected point is correctly classified on the land use and land cover map (Richards & Richards, 2022). Producer accuracy, also known as the error of omission, indicates the probability that the labelling of the classifier is correct in an image pixel. It is determined by dividing the number of correctly classified samples by the total number of reference samples (Richards & Richards, 2022).

Similarly, user accuracy, also known as the error of commission, is produced by dividing the number of correctly classified samples of a particular class by the total number of verified samples belonging to the class (Richards & Richards, 2022). Producer and user accuracies help in assessing if errors are evenly distributed (Congalton, 1991). These accuracy metrics are essential for evaluating the reliability and precision of the classification results and ensuring the validity of subsequent analyses and interpretations.

The Kappa coefficient, which lies between a value of 0 and 1, provides a measure of the difference between the actual agreement and the agreement that would have been expected by chance (Adam et al., 2014). The value of 1 in the kappa coefficient shows perfect agreement between classification and ground truth pixels, whereas a value of 0 shows no agreement (Dorn, Törnros, & Zipf, 2015). The kappa coefficient is calculated using the equation below:

$$\kappa = \frac{N \sum_{i=1}^n m_{i,i} - \sum_{i=1}^n (G_i C_i)}{N^2 - \sum_{i=1}^n (G_i C_i)}$$


where i represents the class number, N is the total number of the pixels classified that are being compared to ground truth, $m_{i,i}$ represents the pixels that belong to the ground class i , that have also been classified with a class i (refers to the values that are found diagonally in a confusion matrix), C_i represents the number in total of classified pixels that belong to class i and G_i represents the number in total of ground truth pixels that belong to class i (Foody, 2002). The overall accuracy, kappa coefficient, and user and producer accuracies were used to observe the level of accuracy and reliability of the LULC maps produced. The confusion matrix using ground truth ROIs was conducted using post-classification tools in ArcGIS 3.2 software.

(e) Change Detection

According to Chen et al. (2012), change detection determines how a feature's state has changed over time by monitoring it at different intervals. Understanding changes in land resources is crucial for planning, regulation, and management purposes (Sunar, 1998). This involves

identifying changes that have occurred, their nature, extent, and spatial distribution (Macleod & Congalton, 1998). Various algorithms and methods are employed in change detection using Remote Sensing (RS) data (Singh, 1989). These methods are based on mathematical and statistical correlations, assumptions, and concepts (Singh, 1989). Some commonly used methods include vegetation index differencing, image differencing, post-classification comparison, principal component analysis, background subtraction, change vector analysis, image digitising, image rationing, image overlay, image regression, and spectral/temporal classification (Singh, 1989; Sunar, 1998).

Although there is disagreement about the most effective change detection strategy, these strategies have been used to monitor changes in various applications and have produced positive outcomes (Singh, 1989). The types of applications, processing constraints, research region geography, and data availability all significantly impact the change detection approaches employed (Lu et al., 2004). Image differencing was the method used for the change detection. This stems from the fact that digital numbers in the resultant difference image are often considered normally distributed where pixels with minor changes are observed around the mean (Zhou et al., 2010). It involves the subtraction of pixels between two co-registered raster datasets to identify areas that have experienced change (Gurgel & Ferreira, 2003). The change was obtained using the LULC maps between 2000-2010 and from 2010-2022. The transition matrix indicating the respective changes from one class to another was calculated from 2000-2022. ArcGIS Pro 3.2 software, which thoroughly tabulated LULC changes between two classed photos, was utilised in the study for its change detection statistics. According to Canty (2019) the change detection statistics provide a class-by-class difference between the images, where the later image is classified as the final state and the earlier image as the starting state. These change detection statistics determined the final state image's classes where the pixels changed. The changes might be presented as areas (expressed in square kilometres for this study), percentages, or pixel counts. The change detection statistics were produced between 2000-2010 and 2010-2022 images. All the classified images were georeferenced before classification and change detection analysis to get accurate results.

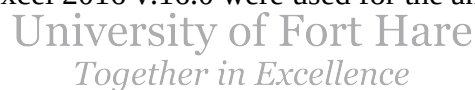
5.2.3 Analysis of land cover change and illegal sand mining detection

The land use land cover change analysis method was utilised for this study to determine changes across various land features such as forest, other vegetation, water, built-up areas, and bare soils over a significant period (Hussain et al., 2020). The land cover change detection

related to illegal sand mining activities along the coastal zone, from the Kei River mouth to the Lubanzi River mouth, was conducted using Esri ArcGIS software. Raster LULC images were converted into vectors to calculate area coverage and change. The intersect geoprocessing method was employed to identify changes across land features between two images over time (Wernette et al., 2017). This analysis was performed for images from 2000 and 2010, as well as from 2010 and 2022, respectively. The results were integrated to generate change detection maps for the two transitions. Additionally, the change detection raster layers from 2000 to 2010 and from 2010 to 2022 were clipped with sand mining extent shapefiles to evaluate the distinctiveness and trend of land use land cover change activities associated with illegal sand mining in the study area.

5.2.4 Transition Matrix

The transition matrix was carried out by exporting each change transition data into an Excel format (Rozario et al., 2017), where further analysis revealed how different land use and land cover had transitioned into another from 2000 to 2022. Consequently, extensive land use and dynamics mapping was conducted to assess illegal sand mining activities along the coastal zone from the Kei River mouth to the Lubanzi River mouth. The XLSTAT engine in Microsoft Excel v.4.2 and Microsoft Excel 2016 v.16.0 were used for the analysis.



5.3. Result and discussion

The land use change dynamics of illegal sand mining activities along the coastal zone from the Kei River mouth to the Lubanzi River mouth were analysed between 2000 and 2022. Land use change dynamics related to illegal sand mining activities were assessed, identifying different classes such as forest, other vegetation, water, built-up areas, and bare soils. Significant changes were observed in the activities of illegal sand mining across the study area during the analysis period, particularly in the classes designated as water, forest, other vegetation, and the built-up regions (Figure 19 and Table 7). Notably, bare soil and other vegetation changes appeared more prominent in the study area in 2000 and 2022. The results reveal that the bare soil class in 2000 accounted for 30.45%, exhibiting the most dominant among the land cover classes, after other vegetation. This indicates extensive human exploitation of sand along the coastal zone. This suggests that the predominant land use change within the study area involves the conversion of bare soil and other vegetated lands to alternative land uses. Various factors,

including socio-economic, climatic, environmental, and physical influences, may contribute to changes in land use and the dynamics of illegal sand mining activities (Mosisa et al., 2023).

The sand mines on or near land are classified as built-up areas and other vegetation, reflecting human disturbances. Furthermore, long-term artificial changes in built-up areas may have facilitated increased sand mining extraction, potentially involving the construction of roads and barriers at the outflows of selected water features, such as rivers (Figure 19).

Table 7: Land cover classes of illegal sand mining.

Year	Forest (%)	Other vegetation (%)	Water (%)	Built-up Area (%)	Bare soil (%)	Total
2000	28.76	36.85	1.95	1.98	30.45	100
2010	30.82	56.74	1.40	6.13	4.90	100
2022	28.45	51.42	1.7	12.8	6.17	100

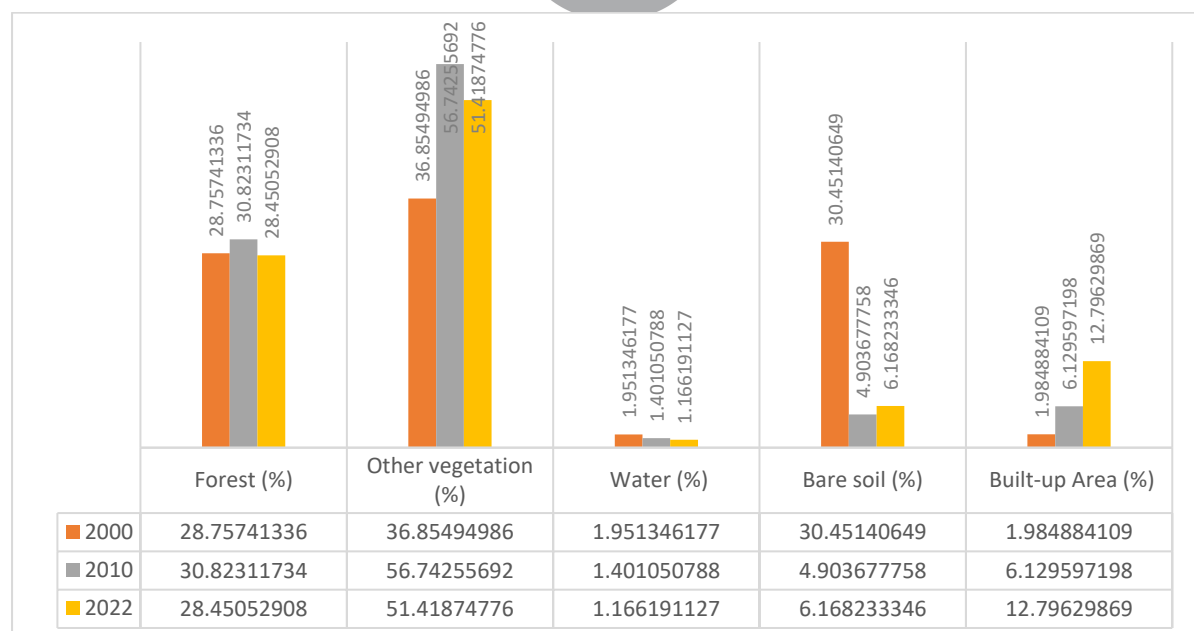


Figure 19: Land-use change dynamics of illegal sand mining.

Figures 20, 21 and 22 show the land use and dynamics of illegal sand mining activities along the coastal zone from the Kei mouth to the Lubanzi River mouth from 2000 to 2022. The results show increased land use as land cover declined across the study period, with forest, water class and bare soil reduced as the built-up areas and other vegetation types gained momentum in growth. The built-up areas indicate an increase in population, which demands an increase in infrastructural development that supports the activities of sand exploitation for habitation (Datta & Deb, 2012; Fashae et al., 2022). Moreover, the presence of other vegetation indicates various human activities such as agriculture, horticulture, and landscaping, which have a direct impact on the growing population along the coastal zone (Al-Maruf, 2020; Emadodin et al., 2020). In the year 2000, the dynamics of illegal sand mining activities were alarming, possibly due to the country being in the early stages of democracy and communities believing that resources belong to them, as shown in Figure 20. However, in the years 2010 and 2022, insignificant differences were observed, indicating a slight increase in bare soil and a decrease in other vegetation.



In 2010, changes were observed in bare soil areas and decreased forest and other vegetation, suggesting a prevalent practice of unlawful access to mining sites for sand extraction (Atampugre, 2010). Additionally, since 2010, enforcement and surveillance efforts to monitor illegal sand mining operations have become somewhat relaxed, directly impacting the coastal zone due to increased illegal sand mining activities (Chaussard & Kerosky, 2016). In contrast, 2022 revealed a significant increase in built-up areas and other vegetation, a rise in bare soils and a decline in forest and water (Figure 22). This may be attributed to intensified sand exploitation activities, resulting in the depletion of natural resources along the coastal zone (Chaussard & Kerosky, 2016).

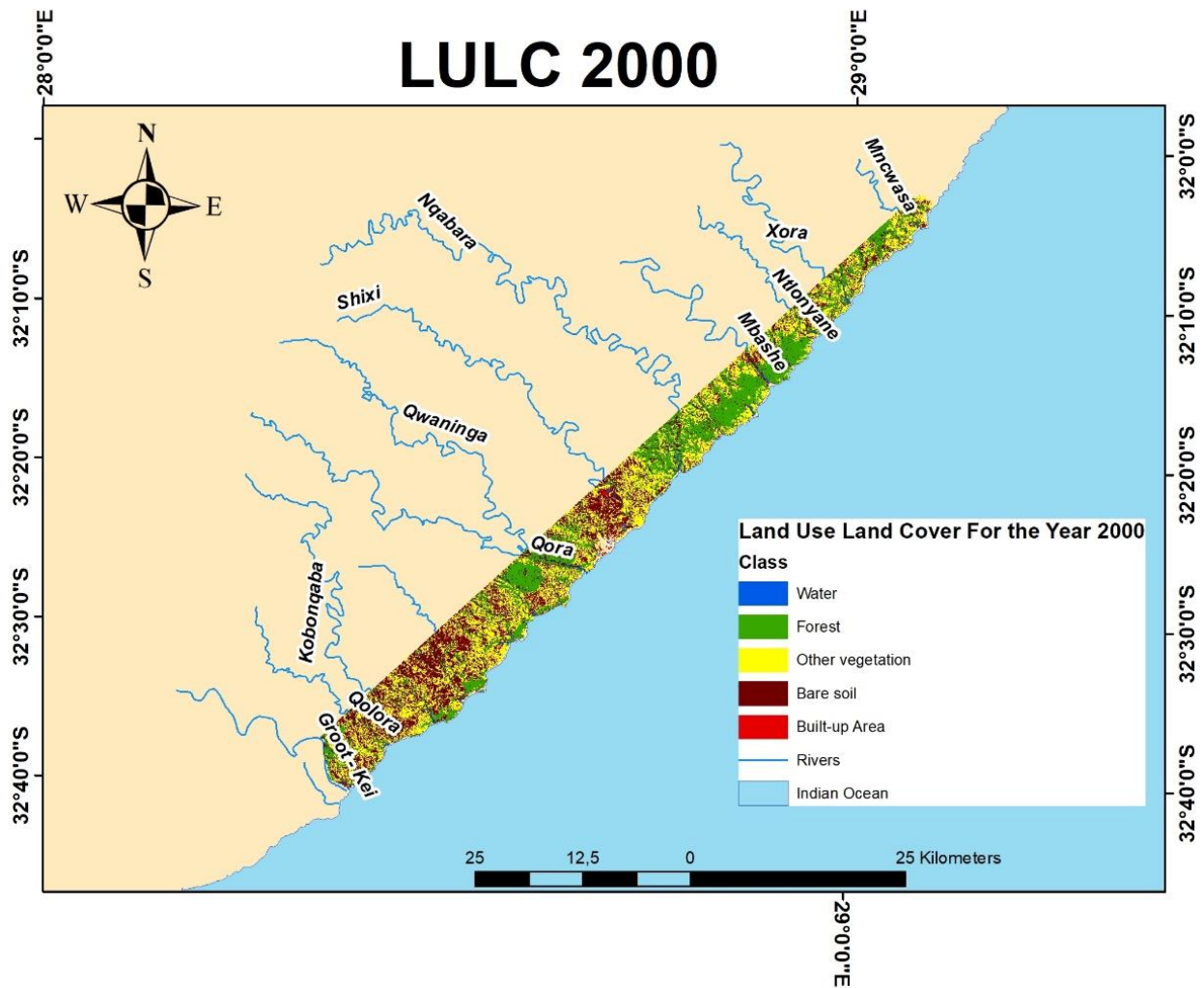


Figure 20: Land-use and land cover dynamics of illegal sand mining activities from 2000.

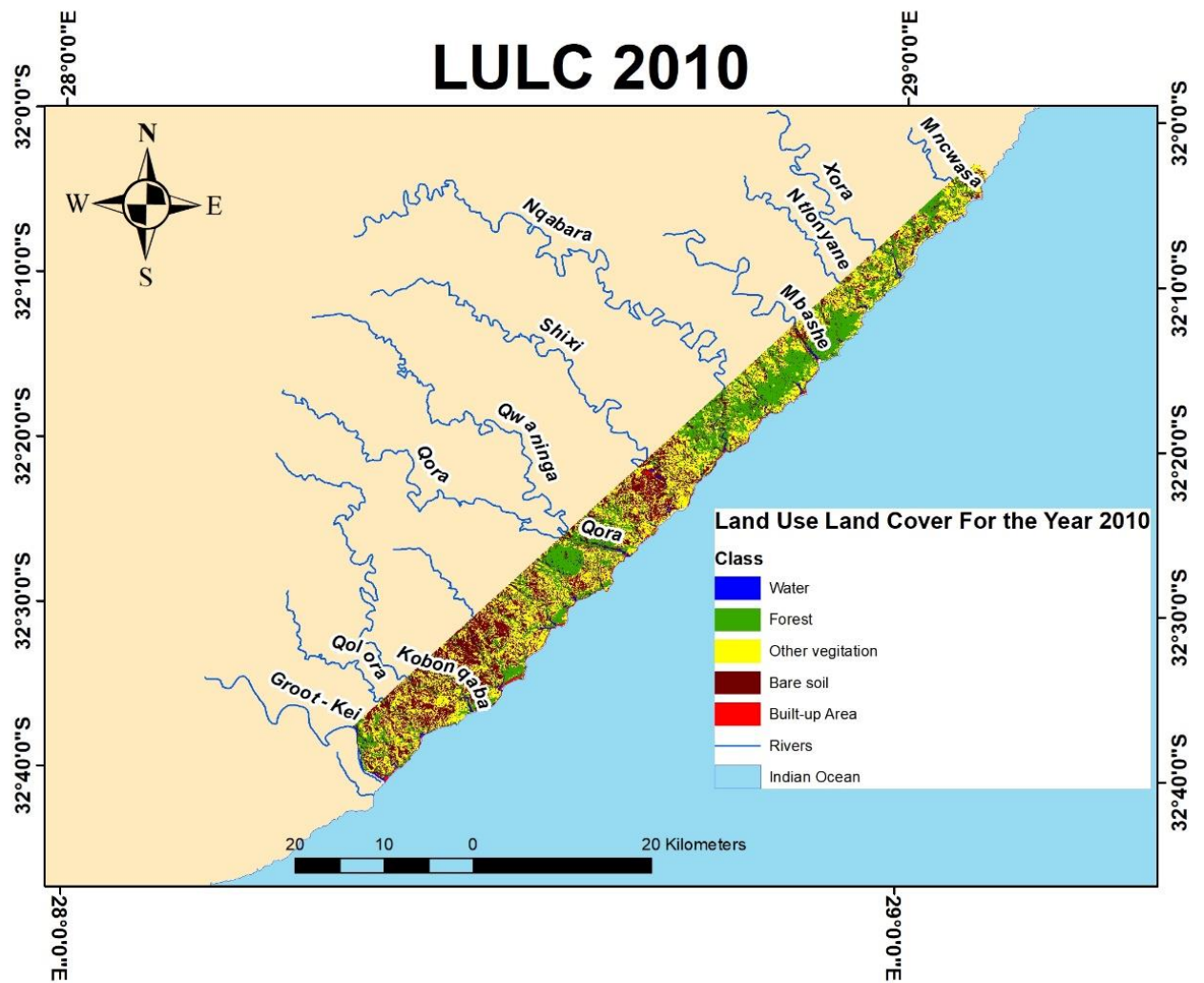


Figure 21: Land-use and land cover dynamics of illegal sand mining activities from 2010.

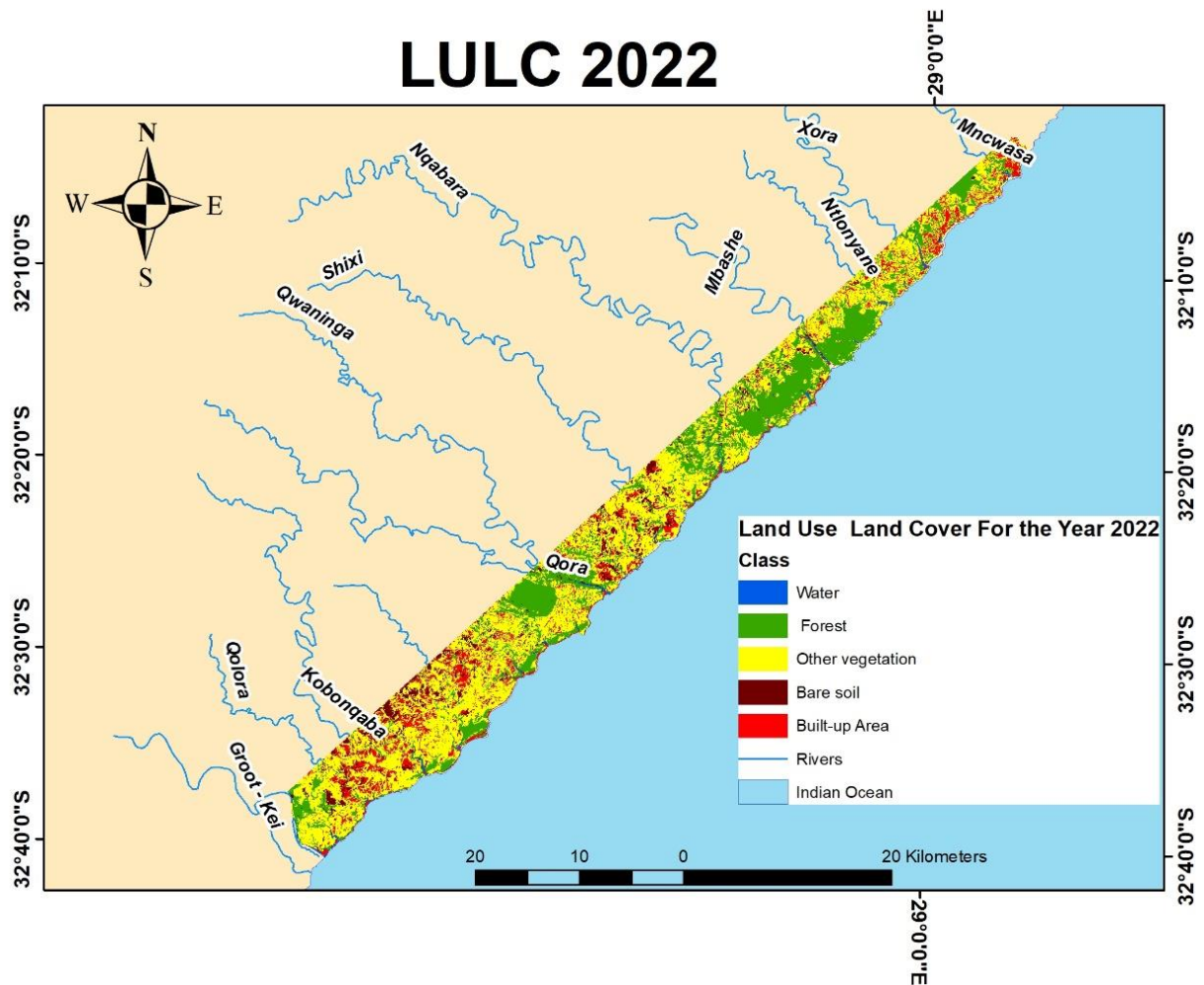


Figure 22: Land-use and land cover dynamics of illegal sand mining activities 2022.

5.3.1. Sand mining and land-use and land cover change.

The total coverage of the study area was 571 km², with the distribution of land use and land cover shown in Table 8. In 2000, bare soil revealed a 30.45% dominant compared to subsequent years (2010 and 2022), primarily due to increased illegal sand mining activities encroaching into vegetated lands. The built-up area also expanded, attributed to road construction for these illegal activities and miners settling in temporary structures. However, there was a significant decline in bare soil coverage, accounting for 25.55% from 174 km² in 2000 to 28 km² in 2010, attributed to law enforcement and regulations prohibiting illegal sand mining activities (Table 8). The gradual resumption of sand mining activities in 2022 resulted in a 1.27% increase in bare soil coverage, from 28 km² in 2010 to 35 km² in 2022, as indicated in Table 8. These trends negatively affect the natural environment, leading to overexploitation of resources in the

area. Such activities pose significant threats to ecosystem-sensitive areas, resulting in the destruction of native vegetation and soil along coastal regions, inland biological corridors, and riverbanks (Kocięcka et al., 2023). This underscores the importance of relevant institutions and diverse stakeholders being fully involved in regulating sand mining extraction and managing natural resources along the coastline.

Table 8: Sand Mining Land Use and Land Cover Change 2000, 2010, and 2022.

2000 LULC Coverage			2010 LULC Coverage		
LULC	AREA_SQKM	AREA (%)	LULC	AREA_SQKM	AREA (%)
Bare soil	174	30.45	Bare soil	28	4.90
Built-up Area	11	1.98	Built-up Area	35	6.13
Forest	164	28.76	Forest	176	30.82
Other vegetation	211	36.65	Other vegetation	324	56.74
Water	11	1.95	Water	8	1.40
Total	571	100	Total	571	100

2022 LULC Coverage		
LULC	AREA_SQKM	AREA (%)
Bare soil	35	6.17
Built-up Area	73	12.80
Forest	162	28.45
Other vegetation	294	51.42
Water	7	1.70
Total	571	100

5.3.2. Change Detection Matrix

The information presented in Tables 9 and 10 compares the classification of land cover statistics, evaluating changes across land use and land cover dynamics. It is evident from these tables that significant changes in the area occur in the other vegetation and forest regions. The increase in bare soil in the early 2000s and the decrease in forest and other vegetation imply consistent and increasing deforestation activities in the study area. Table 9 indicates that the period from 2000 to 2010 saw a slight improvement in physical and climatic conditions, with a reduced drought period. This improvement might have contributed to changes in other

vegetation and forest regions, accounting for 180.2 km² and 14.2 km², respectively (Table 9 and Figure 23). Moreover, other vegetation remains dominant, with a total of 324.4 km², while the bare soil class decreased by 147.0 km² from 2000 to 2010. This decrease in bare soil may be attributed to bush encroachment, grassland growth, or the colonisation of alien species that have covered the bare soil over the years.

Table 9: Land class for years 2000 – 2010 change matrix

		Land class 2010 per km ²					Total
		Bare soil	Built-up Area	Forest	Other vegetation	Water	
Land class 2000 per km ²	Bare soil	17.114	15.330	23.349	116.494	1.660	174
	Built-up Area	0.4923	4.9041	0.0370	4.963270	0.9372	11
	Forest	2.2688	2.6259	136.75	22.33568	0.2911	164
	Other vegetation	5.4674	10.539	14.284	180.2085	0.0279	211
	Water	2.2859	1.5870	1.9955	0.431761	4.8214	11
	Total	27.629	34.987	176.418	324.434	7.738	571

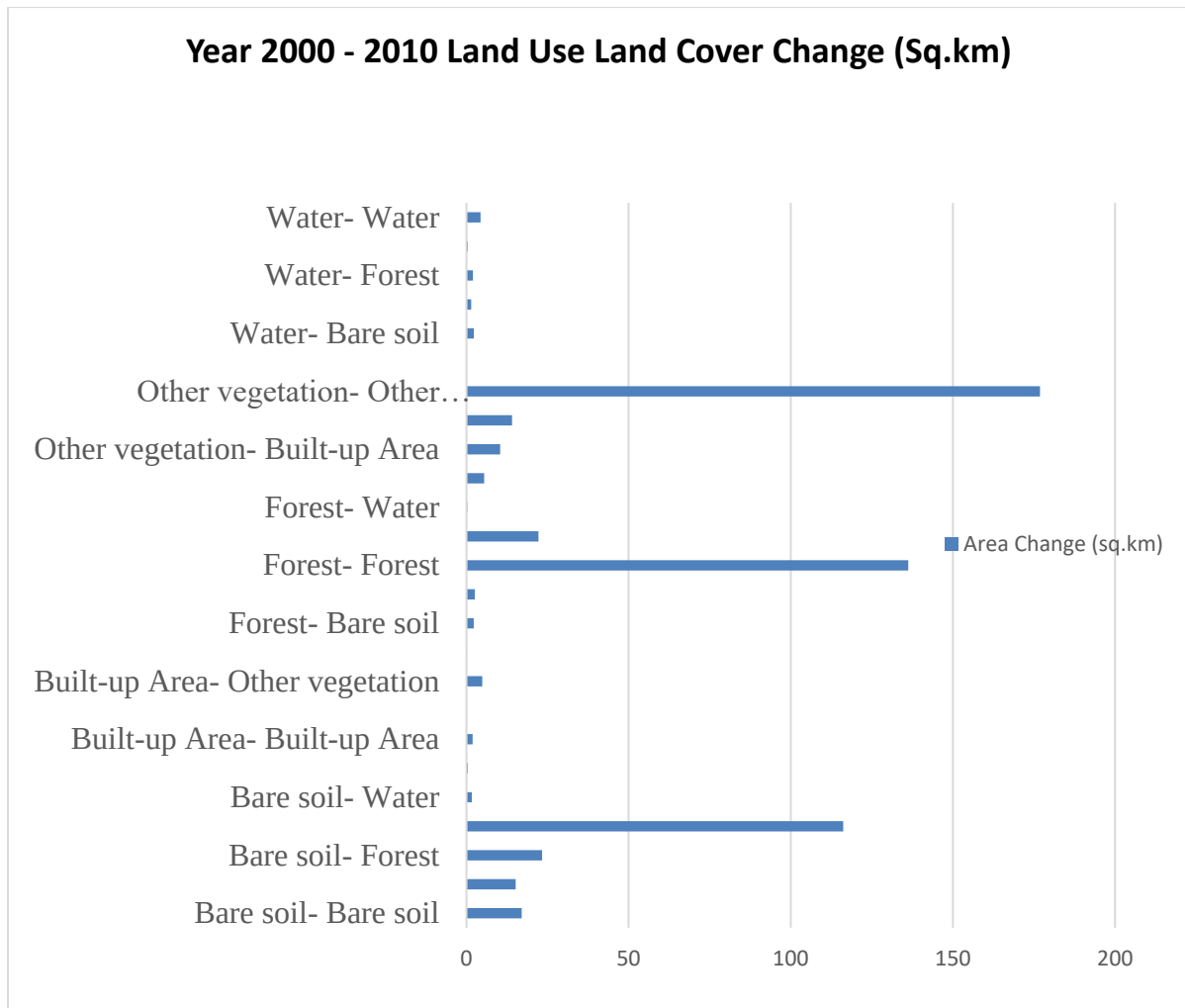


Figure 23: Land-use land cover change (Sqkm) of illegal sand mining activities from 2000 to 2010

Table 10 indicates that the period from 2010 to 2022 witnessed significant rural growth, with built-up areas expanding to 72.6 km². This expansion is attributed to notable agricultural expansion and slight deforestation during this period (Table 10 and Figure 24). The other vegetation region contributed the bulk of land utilised for built-up areas, which accounted for 14.2 km² along the coastal region (Figure 24). This suggests that the bare soil region along the coastline may have exerted considerable influence on other vegetation, soil cover, and dune forest conditions (Marignani et al., 2020).

Table 10: Land class for the year 2010 – 2022 change matrix

		Land Class 2022 per km ²					Total
		Bare soil	Built-up Area	Forest	Other vegetation	Water	
Land Class 2010 per km ²	Bare soil	8.007	2.23	2.56	14.261	0.56	28
	Built-up Area	5.104	9.955	1.210	18.016	0.675	35
	Forest	0.954	0.326	146.940	27.933	0.240	176
	Other vegetation	20.656	59.196	10.477	234.027	0.068	324
	Water	0.451	0.928	1.168	0.221	4.902	8
	Total	35.175	72.638	162.358	294.460	6.447	571

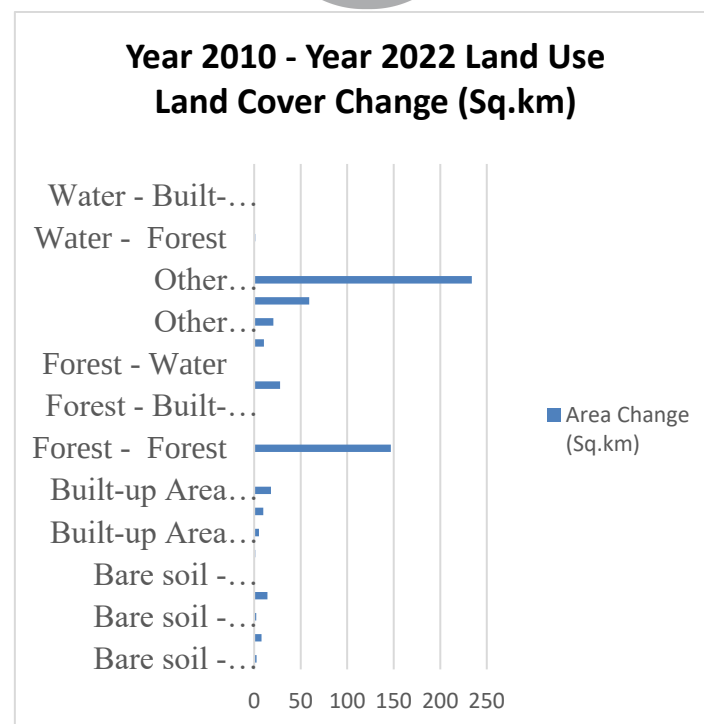
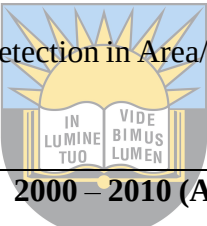


Figure 24: Land-use land cover change km² of illegal sand mining activities from 2010 to 2022

5.3.3. Illegal sand mining change detection from Kei River mouth to Lubanzi River mouth along the Coast

Table 11 and Figure 25 illustrate the land use and land cover changes within the sand mining site. From 2010 to 2022, significant changes occurred, particularly in the forest classes, where more than 20 km² of bare soil was converted to forest land (Table 11). In contrast, between 2000 and 2010, there was a notable change in the water class, with 1.8 km² of water converting to bare soil. However, the changes in the water class between 2010 and 2022 were relatively negligible within the sand mining site. This lack of significant change in the water class during this period may be attributed to the water needing to be retained in the site, as evidenced by the study area's 2022 land use land cover map (Table 11 and Figure 24). This phenomenon could be explained by spatial autocorrelation, where some parts of the rivers appear to be contaminated with sediments (Stiner et al., 2021). Consequently, this contamination might have caused confusion between built-up areas and water classes in some years under investigation.

Table 11: Illegal Sand mining change detection in Area/ km² along Kei River mouth to Lubanzi River mouth



CHANGE	2000 – 2010 (Area /km ²)	2010 – 2022 (Area /km ²)
Bare soil - Bare soil	17.026	8.01
Bare soil - Built-up Area	15.17	2.23
Bare soil - Forest	23.31	2.56
Bare soil - Other vegetation	116.17	14.26
Bare soil - Water	1.62	0.56
Built-up Area - Bare soil	0.44	5.09
Built-up Area - Built-up Area	1.87	9.89
Built-up Area - Forest	0.03	1.21
Built-up Area - Other vegetation	4.86	18.02
Built-up Area - Water	0.13	0.62
Forest - Bare soil	2.25	0.95
Forest - Built-up Area	2.58	0.32
Forest - Forest	136.24	146.93
Forest - Other vegetation	22.22	27.93

Forest - Water	0.28	0.241
Other vegetation - Bare soil	5.45	20.66
Other vegetation - Built-up Area	10.38	59.19
Other vegetation - Forest	14.07	10.47
Other vegetation - Other vegetation	176.87	234.02
Other vegetation - Water	0.025	0.07
Water - Bare soil	2.27	0.45
Water - Built-up Area	1.48	0.94
Water - Forest	1.99	1.17
Water - Other vegetation	0.43	0.22
Water - Water	4.31	0.00

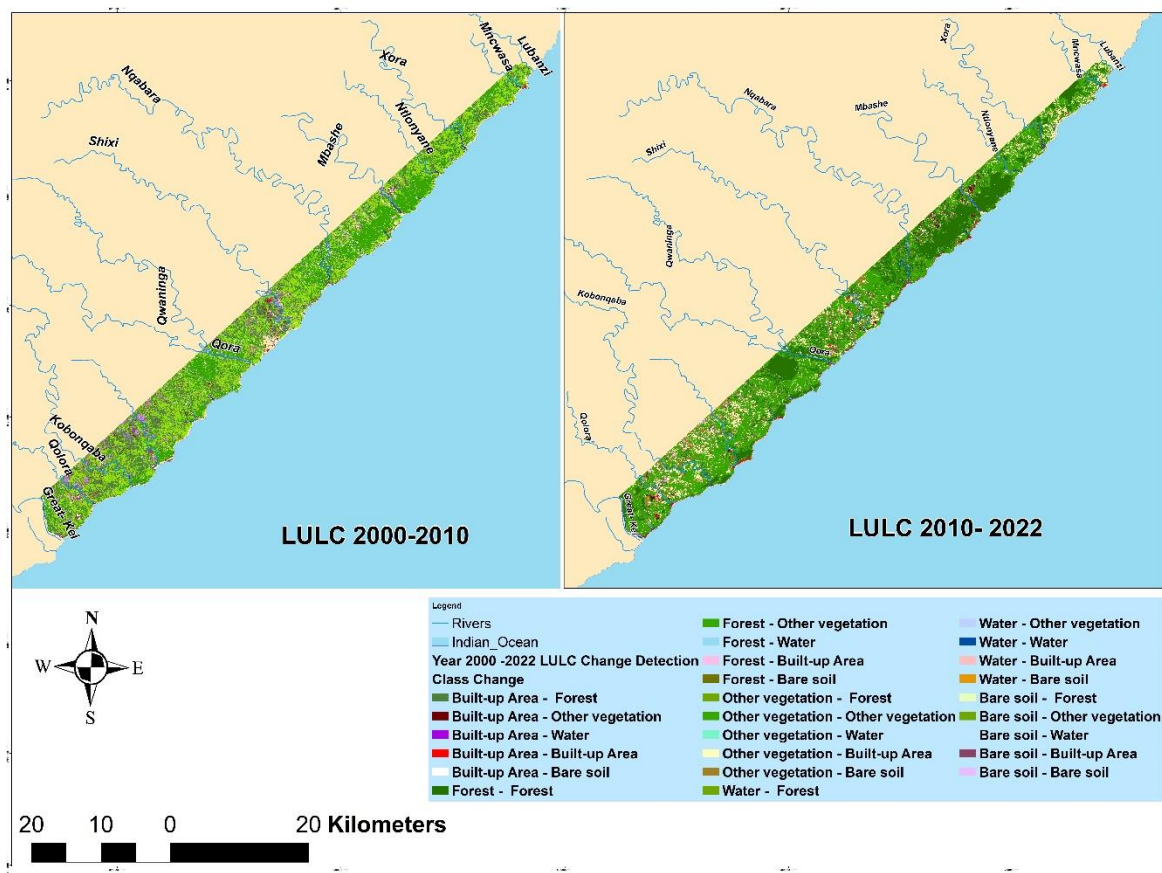


Figure 25: Illegal sand mining change detection classes between 2000 – 2020 and 2010 – 2022

The graphical distribution of land-use land cover changes from 2000 to 2022 is depicted in Table 12 and Figure 25. The most notable land cover changes in illegal sand mining activities occurred in other vegetation lands, such as shrublands, grasslands, dune forests, croplands, etc., totalling 27.1 km² from 2010–2022 (Table 12). Additionally, there was a single instance of forest change in the sand mining site from 2000–2010, coinciding with the commencement of sand mining operations. Consequently, the geographical distribution of land-use land cover changes revealed significant alterations over this period (Table 12). Thus, the exploitation of sand mining became increasingly evident from 2000 to 2022, leading to forest depletion due to encroachment on dune forest conditions along the coast.

Table 12: Sand mining to other land use land cover total change to bare soil

Change	2000 - 2010 (Area/Sq.km)	2010 - 2022 (Area/Sq.km)
Forest - Bare soil	2.25	0.95
Other vegetation - Bare soil	5.45	20.66
Built-up Area - Bare soil	0.44	5.09
Water - Bare soil	2.27	0.45
Total	10,41	27,15

In addition, 2000 – 2010 indicate the period when illegal sand mining activities were the least prevalent, and land cover was protected from the effects of illegal sand mining activities along the coastal zones. However, the illegal sand mining activities gradually began to resurface with the most impact on lands with other vegetation, closely followed by lands with artificial structures, otherwise known as built-up areas. The effects of these changes can be viewed graphically in the chart below, as shown in Figure 26.

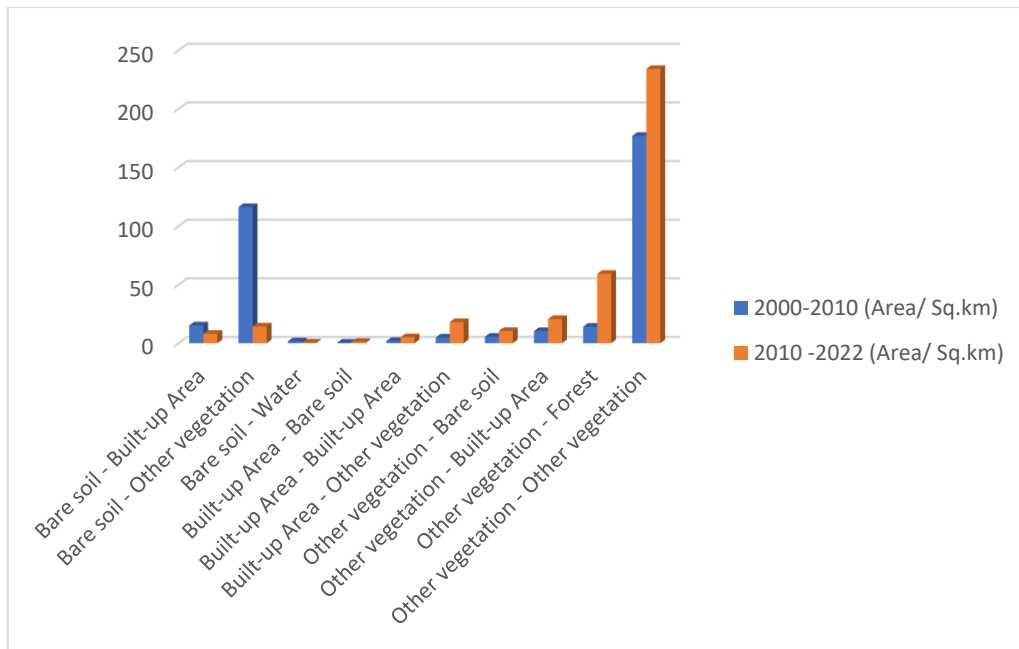


Figure 26: Graphical distribution of the land-use land cover changes across the year 2000 to 2022

Subsequently, other vegetation and forests exhibited variations in their area coverage change to bare soil, as depicted in Figure 27. The results indicate that the transitions from built-up areas to bare soil and from water to bare soil had the lowest total area coverage changes to bare soil. This suggests that the sand mining site transformed significantly from other land use land cover types to bare soil in the study area (Figure 27). Consequently, the loss of forest dune ecosystems and alterations to river sand structures and landscape conditions may have resulted from changes in the other vegetation classes and forest conditions. Between 2010 and 2022, the transition from other vegetation to bare soil showed a substantial increase of more than 20 km², indicating that the effects of illegal sand mining activities were still in the early stages with a negligible impact along the coastal zone. The transition from forest areas to bare soil accounted for 2.2 km² from 2000 to 2010.

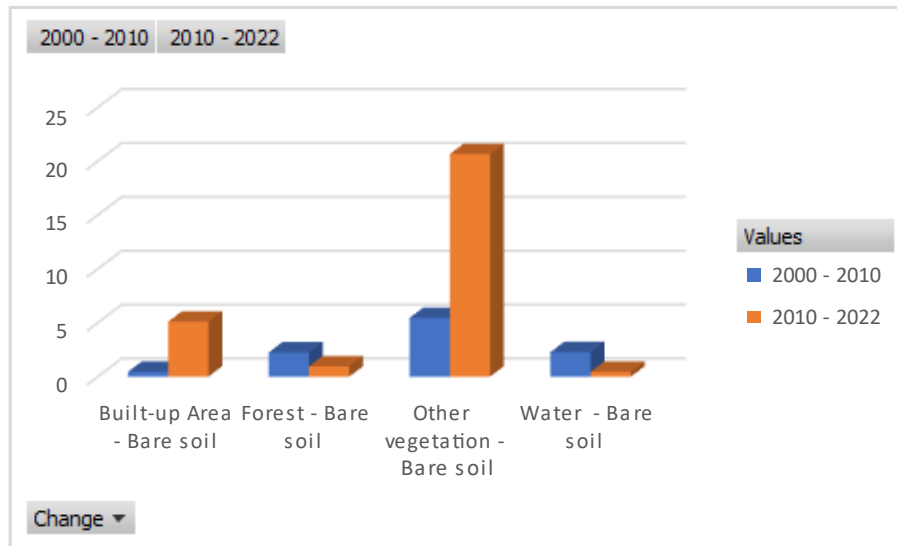


Figure 27: Land use land cover changes from other vegetation area coverage to bare soil.

5.4 Classification accuracy

The consistency of the spatial and temporal trends of the land use and land cover presented in this chapter depends on the accuracy of the imagery's classification. Overall accuracy and Kappa Co-efficient present this. The confusion matrix using the ground truth ROIs module in ArcGIS 3.2 software provides a reliable assessment of classification accuracy by means of the Kappa Coefficient. Classification accuracy assessment is considered substantial if the Kappa Coefficient exceeds 0.70. A classified image can be regarded as accurate if it provides an unbiased representation of the region's land cover. Therefore, the lowest co-efficient in the assessment was 0.72, which is greater than the required value (Table 13)

Table 13: Accuracy assessment for validation 2000, 2010 and 2022

Year	Overall accuracy (%)	Kappa Coefficient	Accuracy Type	Water (%)	Built-Up Area (%)	Forest (%)	Other Vegetation (%)	Bare Soil (%)
2000	90.91	0.88	Producer's	100	100	100	86.4	72.2
			User's					
2010	95.5	0.94	Producer's	94.4	100	94.4	95	94.7
			User's					
2022	97.8	0.97	Producer's	100	100	100	93.8	94.7
			User's					

5.5 Conclusion

This study in the Eastern Cape Province of South Africa aimed to assess the dynamics of land-use change associated with illegal sand mining activities along the Amathole District Wild Coastal Zone from 2000 to 2022. Using Landsat data and various remote sensing techniques, the study analysed changes in land cover, including forest, other vegetation, water, built-up areas, and barren soils. The analysis revealed significant changes in land cover over the study period. In 2000, bare soil accounted for a substantial portion of land cover, indicating widespread sand mining activities along the coastal zone. This suggests that illegal sand mining was prevalent during the early years of democracy in South Africa. However, by 2022, there was a noticeable increase in built-up areas, indicating population growth and infrastructure development driven by sand mining for housing projects and road construction.

The study also found a decline in forest and other vegetation types over the years, highlighting the detrimental impact of sand mining on natural resources such as riparian vegetation and soil quality along coastal regions. Deforestation activities were particularly prominent in the early 2000s, with significant forest cover being converted to bare soil in sand mining zones. Overall, the findings underscore the negative implications of illegal sand mining activities on coastal resources. The study emphasises the importance of regulatory measures and stakeholder involvement in managing and regulating sand mining along the coastline. It calls for innovative approaches to promote sustainable sand mining practices and compliance with existing laws governing natural resource extraction. Furthermore, the study suggests the need for future research to assess global trends and advances in data used in illegal sand mining studies, which could further enhance understanding and management of this issue. Ultimately, the study's outcomes provide valuable insights for coastal environmental stakeholders and decision-makers, informing efforts to optimise the sustainable practice of sand mining excavation along the Wild Coast zone.

Chapter 6: Conclusion and Recommendations

6.1 Introduction

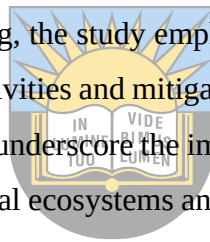
This study showed that sand mining is widespread, and its practice is increasing in developing and developed nations since sand is a high-quality building material found in rivers, lake sediments and dunes. Even though sand is widespread, the demand is rapidly increasing. The increase is mainly caused by building and infrastructure. However, the market made sand mining illegal, and illegal mining activities harm dune forests and riverine habitats. Thus, monitoring illegal sand mining is necessary to minimise the environmental impact. Literature has revealed that conventional techniques are limited to a small spatial extent and labour-intensive for monitoring illegal sand mining. However, spatiotemporal presents an unlimited spatial extent, which is cost-effective and provides timely results for monitoring illegal sand mining. Therefore, the current study was influenced by the unlimited spatial extent of GIS and remote sensing to address the research objectives. This study also used quantitative methods to retrieve the extent of illegal sand mining and land use and land cover changes, which offered insights into trends in this field of research.

The current study has noted illegal sand mining as a global concern that needs to be monitored and reduced through optimum techniques. The wild coast is an international biodiversity hotspot and was selected as a case study for the current study. It is distinguished by a distinct and varied biophysical environment. The Wild Coast, like many other biodiverse ecosystems around the world, faces biodiversity loss and growing human exploitation (Castley, Boshoff, & Kerley, 2001). Both biodiversity protection and landscape beauty are under pressure to suit the demands of the area's underprivileged population while retaining aesthetic appeal (Noble et al., 2014; Simelane & Kerley, 1998).

The physical monitoring methods were unsuitable for this study because of their limitations. Therefore, this study investigated the utility of the spatiotemporal to assess the extant impacts of illegal sand mining along the wild coastal area of the Amathole region. To guide this research, the two objectives were developed, and key findings are summarised as follows:

Objective one. A comprehensive study assessed the spatial and temporal trends of illegal sand mining, precisely the size of sand pits, along the coastal zone stretching from the Kei River mouth to the Lubanzi River mouth over the past 22 years (2000 – 2022). The investigation identified a minimum of 24 illegal sand mining sites, with findings indicating a significant

growth in these activities over time, varying depending on the location. Physical damages resulting from illegal sand mining were observed across most areas, including the aftermath of activities such as sand pit dumping. The study hypothesised that one of the primary drivers behind this growth is the rapid expansion of the human population. Using aerial imagery from 2000 to 2022, remote sensing techniques and GIS tools were employed to analyse illegal sand mining along the Eastern Cape coast thoroughly. The research unveiled a concerning escalation in these activities throughout the observed period. Among the notable findings was identifying 24 coastal sites engaged in illegal sand mining, with only one site showing inactivity during the data collection period. The spatial extent of these activities witnessed a significant increase from 2000 to 2022, with notable expansion observed across various sites along the coast. Change detection analysis revealed a substantial surge in illegal sand mining, amounting to a total difference of close to 149.734 km² over the past 22 years. Contributing factors to this rise included inadequate legislation and law enforcement, the creation of job opportunities, and the rapid population growth driving the demand for construction materials. Despite the socioeconomic benefits of sand mining, the study emphasises the urgent need for more robust regulatory measures to curb illegal activities and mitigate the environmental impacts caused by unauthorised extraction. The findings underscore the importance of continuous monitoring and enforcement efforts to safeguard coastal ecosystems and communities from the adverse effects of illegal sand mining.



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Objective two. To assess the impact of illegal sand mining activities on the landscape dynamics (i.e., land use change and vegetation cover change) in the study area. Analysing illegal sand mining activities along the coastal zone from the Kei River mouth to the Lubanzi River mouth between 2000 and 2022 revealed significant shifts in land use dynamics. Over this period, there were noticeable transformations in various land cover classes, particularly in forests, other vegetation, water, built-up areas, and bare soils. Of particular concern was the considerable increase in bare soil, indicating extensive human exploitation of sand along the coastal zone and the escalating impact of illegal sand mining activities on the environment and land cover. Between 2000 and 2010, there was a gradual rise in bare soil coverage, primarily attributed to intensified illegal sand mining operations encroaching into vegetated lands. However, enforcement efforts led to a decline in bare soil coverage by 2010. Subsequently, from 2010 to 2022, there was a resurgence in illegal sand mining activities, increasing in built-up areas and other vegetation, alongside a rise in bare soils and a decline in forest and water.

Notably, the transition from other vegetation to bare soil signified the early stages of the impact of illegal sand mining activities. In contrast, changes from forest areas to bare soil underscored the loss of forest dune ecosystems due to sand mining. These findings underscore the urgent need for robust regulatory measures and stakeholder involvement to mitigate the adverse effects of illegal sand mining on coastal ecosystems. Furthermore, the classification accuracy assessment demonstrated a reliable representation of land cover changes over the study period, with overall accuracies exceeding 90% and Kappa coefficients indicating substantial agreement between classified images and ground truth data. This underscores the validity of the analysis and reinforces the urgency of addressing illegal sand mining activities to preserve coastal ecosystems and biodiversity.

6.2 Recommendations

The current study utilised Landsat and aerial images to assess the extent and impacts of illegal sand mining, employing spatiotemporal-quantitative methods to analyse trends and advancements in data and modelling for monitoring illegal sand mining. However, future studies are encouraged to explore multiple databases and use various analytical techniques, such as meta-analysis or systematic review, to enhance understanding. Since sand mining is a daily activity and monitoring it every three months may not be effective, conducting weekly flights using drones or aerial surveys is recommended. This frequent monitoring can provide real-time data and better insights into the dynamics of illegal sand mining activities. Existing literature suggests that legislation alone may not be sufficient to minimise illegal mining. Therefore, it is recommended that the government revises legislation to accommodate small-scale sand miners for subsistence use while ensuring sustainable management of resources. Additionally, incorporating Extended Public Works Programs (EPWP) to monitor illegal sand mining could be beneficial. EPWP initiatives have succeeded in other sectors, such as Working for Water, Fire, and Forests. Hence, the research suggests implementing a "Working for Sand" program. Furthermore, the study recommends identifying sites that are feasible for sand mining to be licensed, thereby promoting legal and regulated extraction practices while minimising environmental degradation and socio-economic impacts.

6.3 Limitations of the Study

The study encountered several limitations that may have affected the comprehensiveness and accuracy of the findings. Firstly, the analysis relied on only one database for assessing trends in illegal sand mining, potentially overlooking essential data sources that could provide additional insights or corroborate findings. Secondly, the study area on the wild coast presented challenging terrain and limited accessibility to certain areas. This limitation hindered the researchers' ability to access and survey all sites of interest, potentially resulting in gaps or biases in the data collection process. Furthermore, restricted movement between sites due to terrain conditions may have affected the thoroughness of the assessment. During fieldwork, researchers also encountered instances where sand miners mistook them for law enforcement officials, leading to potentially dangerous situations. This may have impacted the researchers' ability to gather information or conduct surveys in certain areas. Despite these limitations, the study aimed to cover the entire area of interest to the best of its ability, and efforts were made to mitigate the challenges associated with the rugged terrain and potential safety concerns. However, it's important to acknowledge these limitations when interpreting the study's findings and conclusions.



6.4 Future Research Agenda

The widespread nature of illegal sand mining across the continent poses significant threats to ecosystems and exacerbates climate change. Monitoring these activities, particularly in international biodiversity hotspots, is crucial for effective environmental management and conservation efforts. Integrating Geographic Information Systems (GIS) and remote sensing techniques has effectively monitored illegal sand mining activities, providing valuable resource management and policy development insights. Future studies in this field can leverage advanced satellite imagery from platforms such as Landsat and Sentinel, comparing their accuracy and suitability for monitoring sand mining activities. Additionally, while the extent of mined areas is essential, future research should also focus on quantifying the volume of sand extracted and its impact on local ecosystems and hydrology. Understanding the dynamics of sand markets and the drivers behind illegal mining activities can provide valuable context for developing targeted interventions and regulatory frameworks. Furthermore, there is a need for comprehensive global research mapping trends and advances in data used in illegal sand mining studies. By synthesising existing knowledge and identifying research gaps, future studies can

contribute to a more holistic understanding of the phenomenon and inform evidence-based policy interventions locally and globally.



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