Crop fields abandonment: assessing the dynamics of degradation in relation to leverage points for sustainable land management in the Macubeni catchment, South Africa

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Abstract

Soil erosion is a major global environmental problem and a pervasive forms of land degradation that threatens land productivity and food and water security. Some of the biggest sources of sediment in catchments are previously cultivated lands. Regardless of this factor, the abandonment of cultivated fields is not well-researched. Sustainable land management (SLM) interventions can play a significant role in mitigating and halting land degradation. This study investigated the dynamics of degradation exhibited by crop fields and the potential impacts of SLM interventions, using a leverage points framework and a case study in the Macubeni catchment of South Africa. The research answers three questions: (1) What is the relationship between the usage status of crop fields and degradation in Macubeni? (2) What are the drivers of crop field abandonment and how do they interact in the system? (3) Can proposed sustainable land management interventions tackle the dynamics of land abandonment, and associated degradation, at the root cause level? An empirical-analytical approach using a four step multi-method process was followed, in which crop fields were mapped using ArcGIS tools, literature was reviewed alongside stakeholder engagements, qualitative systems mapping modelling was undertaken, and a Multi-Criteria Analysis (MCA) with leverage points hierarchy was used to integrate all the steps together. The results revealed that the various drivers of crop field abandonment include natural environmental factors, socio-economic and social factors. 47.41% of the total crop fields in Macubeni were classified as highly degraded, and abandoned fields covered 37.47%. The statistical Chi-Square Test also confirmed that there is a significant relationship between the usage status and degradation level in crop fields. The SLM interventions assessed in the study have the potential to tackle the dynamics of land abandonment at a root cause level, however, there is a need to first shift the community's mental models to address the existing sources of change resistance that are hindering successful implementation. Furthermore, the innovative multi-method approach applied in this study can further provide a holistic, dynamic, and integrated decision-support to land conservation and rehabilitation projects in similar settings across South Africa and other developing countries as opposed to the more traditional one-dimensional approaches.

Key words: *abandoned fields, degradation, sustainable land management,* systems mapping*, Multi-Criteria Analysis, leverage points*

Plagiarism declaration

I, Silindile Sibiya, have read and understood the Rhodes University plagiarism policy and declare that this research report, apart from the contributions acknowledged in the respective sections, is my own unaided work. It has not been presented before for any degree or examination to any other institution of higher education.

Signature:

Date: 3 March 2023

Disclaimer

The core parts of this research are reflected in a paper that has been accepted for publication to the journal Land (published by MDPI) [Manuscript ID: land-1998346], doi: 10.3390/land12030606. Volume 12, 2023. The manuscript is hereby included as Appendix B.

Dedication

I would like to dedicate this report to the most loving and supporting human being in my life, my mother! Thank you mom for always being there for me and encouraging me throughout the entire process of producing this thesis, especially when I needed it the most.

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List of abbreviations

CBA - Cost Benefit Analysis

CBA - Cost-Benefit Analysis

CLD -Causal Loop Diagram

CV - Critical Value

EIA - Environmental Impact Assessment

ELD - Economics of Land Degradation

ELM - Emalahleni Local Municipality

GEF5 - Global Environment Facility (5th funding cycle)

GIS – Geographical Information System

IAPs – Invasive Alien Plants

KZN – KwaZulu Natal

LCA - Conservation Activists

MADA - Multi-Attribute Decision Analysis

MCA - Multi Criteria Analysis

MCDA - Multi Criteria Decision Analysis

NDVI – Normalised Difference Vegetation Index

NDVI - Normalized Difference Vegetation Index

NIR – Near infrared

RUSLE - Revised Universal Soil Loss equation

SA – South Africa

SD - System dynamics

SLM – Sustainable Land Management

UN – United Nations

UNCCD	United Nations Convention to Combat Desertification
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
WOCAT	World Overview of Conservation Approaches and Technologies

Units of measurement

m - metre

m^3 – cubic metres

Mha – Million hectares

mm – millimetre

mm/hr – millimetre per hour

mm/yr - millimetre per year

ha - hectare

km^2 – square kilometres

t/ha/yr – tons per hectare per year

Chapter 1. Introduction

1.1. Background

Research has shown that soil erosion is a global environmental problem and one of the biggest forms of land degradation (Sepuru and Dube, 2018). The Economics of Land Degradation (ELD) Initiative revealed that up to 20% (~12 million square kilometres) of the earth's surface land is degraded (ELD Initiative, 2015). Africa is the most vulnerable continent that is most severely affected by land degradation, with 45% of the continent threatened by desertification (ELD Initiative, 2015). This ruinous effect in Africa particularly affects agricultural lands, hindering food security (ELD Initiative, 2015). In addition, 52% of the world's agricultural land is moderately to severely degraded (Sepuru and Dube, 2018). It is acknowledged across the literature (Dollar and Rowntree, 1995; Meissner et al., 2013; Rienks et al., 2000; Seutloali et al., 2017; Valentin et al., 2005) that land degradation is a natural phenomenon caused by events such as global climate change and natural geomorphological processes. However, it is often exacerbated by human activities, such as intensive agricultural practices that lack proper conservation techniques, for example inappropriate cultivation and overgrazing (Seutloali et al., 2017; Valentin et al., 2005).

In South Africa, soil loss is 8 to 30 times faster than soil formation (Seutloali et al., 2017).This subjects about 1Mha of land to very high erosion rates (Seutloali et al., 2017). With that said, the risk of soil erosion, except for zero tillage technique, has been claimed to increase even further when the land is cultivated (Huchzermeyer et al., 2018). This is due to the soil structure being disturbed and soil being exposed to rainfall erosive effects (Huchzermeyer et al., 2018). Flowing water being the main agent of erosion, it overcomes the surface resistance and results in soil detachment as it concentrates into sloping depressions (Rowntree, 2016). In effect, the process may strip the fertile nutrient-rich topsoil from cultivated lands, leaving them unproductive and leading to fields being abandoned (Le Roux, 2011; Parwada and Van Tol, 2016). Multiple studies have documented a trend in the increase of abandoned fields in Southern Africa (de la Hey and Beinart, 2017; Jewitt et al., 2015). As these fields are left abandoned, with no vegetation cover to hold the soil, sediment yield increases further, making these abandoned fields erosion hotspots (Huchzermeyer et al., 2018) and triggering the formation of gullies (Valentin et al., 2005). As highlighted by Ravi et al. (2010), one of the main sources of sediment is gullies, and gullies are a big part of the land degradation in South Africa. Similar to Pandey et al. (2007) study, this research employs a spatial analysis method through the use of ArcGIS to investigate areas prone to degradation and in effect, identify priority areas for land rehabilitation practices.

The sediments from cultivated lands and erosion features such as gullies, are transported and deposited into water bodies. This reduces their capacity and negatively affects water use and ecosystem health due to high siltation (Le Roux et al., 2013). Siltation of water resources is one amongst many detrimental effects of soil erosion and one of the biggest concerns in dammed catchments. For example, within only twenty years after completion, the Welbedacht Dam capacity in South Africa reduced rapidly from 115 million m^3 to 16 million m^3 due to siltation. Consequently, an offsite purification process was required due to high sedimentation concentration in the water, which costs about R2 billion per annum (Le Roux, 2011). This emphasises the importance of implementing mitigation practices for soil erosion control, thus enabling smart management of dams and reservoirs (Brambilla et al., 2015).

Sustainable land management (SLM) is one way to address land degradation. SLM “technologies” as termed by the World Overview of Conservation Approaches and Technologies (WOCAT), refer to the physical practices that control land degradation and enhance productivity (Sanz et al., 2017). SLM “technologies” are widely promoted and accepted in many countries in Africa (Sanz et al., 2017). In essence, SLM is based on the key principles of enhancing the productivity and protection of natural resources, while being economically viable and socially acceptable (Schwilch et al., 2014). It encompasses soil, water and vegetation conservation measures and encourages an integrated and holistic perspective of land management (Liniger et al., 1999; Schwilch et al., 2014). Moreover, the most common SLM practices that are implemented to address land degradation on cultivated lands are related to preventing soil erosion and soil deterioration, and improving productivity and biodiversity (Sanz et al., 2017). These include the following SLM technologies: soil erosion control, integrated soil fertility management, minimum soil disturbance by tillage, vegetation management, sustainable irrigation systems, drainage and water harvesting. SLM activities often mitigate soil erosion through reducing surface runoff by structural or vegetative barriers and/or by increasing soil cover (Sanz et al., 2017). This study focuses mainly on the SLM practices for soil erosion control. As concluded by Sanz et al. (2017), the continued global increase in land degradation indicates that there is still a gap between acknowledging SLM practices and reaching their successful implementation.

Furthermore, various interconnections such as drivers of soil erosion, factors which affect the use of crop fields or lack thereof, along with the SLM impacts, are all indicative of the intricacy of the socio-environmental system. This further warrants the application of systems thinking as a tool for assessing these connections. As defined by Kim (1999), systems thinking is a school of thought that allows one to identify the interconnections of different components in a system and then unify those components to get a holistic view of that system. A systems approach to solving complex problems has been increasingly promoted within various disciplines, such as drug use social studies (Pruyt, 2009), natural resource management (Ewert and Giller, 2006), and agriculture (Turner et al., 2016). As a result, several discoveries made through the use of systems thinking have led to sustainability actions that would not have been otherwise feasible from a siloed approach (Banson et al., 2014; Liu et al., 2015; Phelps et al., 2013); hence its application in this study. In addition to that, a broad category of structured approaches known as Multi Criteria Analysis (MCA) tool is used to integrate the spatial analysis and the systems diagramming methods. This is a valuable addition to the methods used because it enables the simultaneous comparison of interventions in terms of their impact in the catchment using different criteria. This approach is commonly used within the sustainable development space due to its ability to process complex systems (Karlson, M. et al., 2016; Zhang et al., 2013; Zia et al., 2011).

1.2. Problem statement

Previously cultivated lands are major sources of sediment in catchments and are a concern in arid areas globally (Blair et al., 2018). Sedimentation drives the siltation rate of dams and rivers, which reduces dam capacity and poses a water security threat to many regions. The Macubeni catchment in the Emalahleni Local Municipality in the Eastern Cape of South Afrcia is one such region and is the study site for this research. Sustainable land management practices (such as stone lining of gullies and rotational grazing) control land degradation, enhance productivity, and encourage integrated and holistic land management (Schwilch et al., 2014).

Furthermore, following Sanz et al. (2017), the most effective implementation of SLM practices are those that address water and soil conservation, the diversification of cropping systems, and the integration of crop and livestock systems. However, the effectiveness of SLM in the context of the various factors that affects their success or failure is not well researched. Therefore, this study assessed the level of degradation in crop fields, drivers of crop fields abandonment and the impacts of SLM interventions, using a combination of spatial analysis through GIS and temporal analysis through system dynamics and multi criteria analysis.

1.3. Motivation and context of study

The Eastern Cape is one of the South African provinces most severely affected by erosion, where an estimated 151 759 ha of land is degraded by gullies and the soil loss rate exceeds 12 t/ha/yr (Msadala et al., 2010) (see Chapter 3 for details of the study area). For this reason, the Eastern Cape Province (specifically Baviaanskloof and Macubeni) is one of the Global Environment Facility (GEF5) Sustainable Land Management (SLM) Project’s pilot areas, aimed at rehabilitating degraded landscapes. The aim of the GEF5 SLM Project is to enable the adoption of sustainable land management practices and ecosystem rehabilitation in support of the green economy and resilient livelihoods. The GEF5 SLM practices are defined here according to three of the project’s hubs: i) Land rehabilitation hub, which uses low cost land rehabilitation techniques such as stone lines, brush silt traps and stone packs to trap silt and rehabilitate the degraded landscape; ii) Livestock and Rangeland management hub, which includes shifting from open-access grazing regimes to more sustainable practices, such as resting and rotational grazing; and iii) Conservation agriculture hub, which involves training community members on conservation agriculture principles such as mulching (soil cover), crop rotation (plant diversity) and minimum tillage (minimum soil disturbance).

As evidence of the soil erosion challenges, in one of the GEF5 SLM Project stakeholder workshops, the Emalahleni Local Municipality officials raised a concern that the Macubeni dam is silting up. This is a major issue for the municipality because the dam is the main water supply for the surrounding villages and local town (Lady Frere, now called Cacadu). Therefore, the dam siltation poses a water security threat for the whole catchment. As a result, the GEF5 SLM Project made motion to determine the lifespan of the Macubeni dam in relation to the siltation rate and dam capacity. Subsequently, this study downscales from that project to focus on the erosion from crop fields and mapping the potential impact that the GEF5 Project SLM activities may have on addressing the dynamics around crop land abandonment using a systems thinking approach. Systems thinking allows one to approach a problem holistically and realise how different components interact with each other in the system rather than in silos (Meadows, 2011) and minimises short-sighted decision making. This makes it a suitable tool for use in this study.

Furthermore, using a systems thinking approach to investigate the potential impact of SLM practices, facilitates and promotes holistic land management that is inclusive of socio-cultural, environmental and economic aspects. The qualitative model can be used to provide dynamic and integrated decision-support for policy implementation in land management practices in the study site and help build stakeholder understanding of the impacts of SLM practices in degraded areas. In essence, SLM practices can support the transition to more sustainable livelihoods in a changing world.

1.4. Research Aim

The main aim of this study was to investigate the degradation exhibited by crop fields in Macubeni, and the potential impact of SLM interventions on mitigating drivers of land abandonment.

1.5. Research questions

1. What is the relationship between the usage status of crop fields and degradation in Macubeni?

2. What are the drivers of crop field abandonment and how do they interact in the system?

3. Can proposed sustainable land management interventions tackle the dynamics of land abandonment, and associated degradation, at the root cause level?"

1.6. Objectives

1. To map and classify the extent of land degradation on currently cultivated and previously cultivated lands in Macubeni.

2. To develop a qualitative systems model using causal loop diagrams to describe and analyse the interactions between crop fields abandonment, degradation and associated SLM interventions.

3. To determine the leverage points of different SLM interventions and synthesise with the Multi Criteria Analysis for an assessment of their potential impact on addressing land abandonment.

1.7. Thesis structure

This study consists of seven chapters in total and is structured as follows:

Chapter 1: Introduction

This chapter has introduced the study and provided a broad overview of the research, including a brief overview of soil erosion, SLM activities, and the drivers of crop field abandonment, alongside the study rationale, aims and objectives, and research questions.

Chapter 2: Literature Review

This chapter reviews the literature and gives insight into the arguments put forward by other authors, along with their discoveries.

Chapter 3: Study area

The locality and environmental characteristics of the area within which this research was conducted are provided in this chapter.

Chapter 4: Research Methods

The fourth chapter provides the description of the methods employed to map out the degradation levels on cultivated and previously cultivated fields, the sources and how they are accessed. It further details the process that was used in modelling the interactions between drivers of erosion and impact of SLM activities.

Chapter 5: Crop fields results and analysis

This chapter provides the results and analysis of the crop fields in the study area using maps, graphs and tables to illustrate the findings on degradation and abandonment.

Chapter 6: Model Conceptualisation and interventions

This chapter outlines the concept behind modelling the various interconnected factors which drive crop fields abandonment and how SLM activities can influence the system in order to bring about positive change.

Chapter 7: Discussion and conclusion

General conclusions about the complete study and findings are drawn in this chapter with reference to the core objectives of the study. Limitations and recommendations on what can be done in future studies to further investigate agricultural land abandonment and its dynamics, are stated.

Chapter 2. Literature review

2.1. Introduction

Land degradation has been a challenge faced by countries from several different climatic conditions and land use changes around the world (Sanz et al., 2017; UNCCD, 1994). The UNCCD (1994), as described in Sanz et al. (2017, p. 18), defined land degradation as "the reduction or loss of the biological or economic productivity and complexity of rainfed crop land, irrigated crop land, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical and biological or economic properties of soil; and (iii) long-term loss of natural vegetation". This has been reported by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) to be a global issue that affects the wellbeing of 3.2 billion people on average IPBES (2018). This means several national economies and communities are vulnerable to climate change and exposed to food insecurity and poverty (IPBES, 2018).

As a result of continued land degradation processes through climatic changes and human activities in drylands, the decrease in land productivity and overall ecosystem services persists and results in poverty and starvation, people migrating, and abandoning their lands (Sanz et al., 2017; UNCCD, 1994; Verstraete et al., 2009). This is defined as desertification, and is inclusive of both the biophysical and social aspects (UNCCD, 1994; Verstraete et al., 2009).

Geist and Lambin (2004) highlighted that the causes behind desertification have been rather controversial in literature. Some authors (i.e. Breckle et al. 2002; Le Houérou, 2002) argue that it is the ever-increasing human population leading to the overuse of land resources, thus irreversible degradation of land that ultimately results in desertification (i.e. man-made deserts) . On the other hand, it is suggested that land desertification is caused by multiple factors (which include both socio-economic and biophysical) that act together in different scales and are locality specific (Lambin et al., 2001; UNCCD, 2017a; Verstraete et al., 2009; Warren, 2002). ELD Initiative & UNEP (2015) concur with researchers (i.e. Lambin et al. 2001a; Verstraete et al. 2009; Warren, 2002) that attribute the underlying causes of desertification to a combination of both the biophysical and the socio-economic conditions.

Some researchers (e.g. Sepuru and Dube (2018)) argue that soil erosion is one of the biggest forms of land degradation, hence it being the focal point of discussion in this study. Studies further assert that inasmuch as land degradation is a natural phenomenon, its ruinous effects are often exacerbated by human activities through their different land use systems (Hoffman and Todd, 2000; Seutloali et al., 2017; Valentin et al., 2005). Indicative of this claim, some of the biggest sources of sediment in catchments have been found to be previously cultivated/abandoned fields (Hebinck et al., 2018). In addition, 52% of the world's agricultural land is moderately to severely degraded (Sepuru and Dube, 2018). I review the drivers of land degradation and its impacts on the environment and people, crop agricultural land abandonment, and SLM practices that are implemented to address land degradation on crop lands. As mentioned in the first chapter, SLM is the holistic approach of managing and preserving the ecosystem's long-term productivity (Sanz et al., 2017). Lastly, the use of systems mapping as an overarching tool to deal with complex interconnected components of a phenomenon such as land degradation, is also reviewed.

2.2. Causes of land degradation

2.2.1 Catchment hydrology

Historically, several studies such as Horton (1933) cited in Peters (1994), Hewlett (1961) and Dunne (1978) both cited in Burt (1989), have identified rainfall and runoff to be some of the most significant environmental components which contribute to the occurrence and extent of soil erosion in a catchment. Horton (1933) cited in Peters (1994) for example, almost a century ago, concluded from his study that concentrated runoff will occur whenever the intensity at which the rain falls, exceeds the capacity of surface infiltration. However, Hewlett (1961) later challenged Horton's theory by arguing that the saturated areas within a catchment are the determinant factors for the frequency and total volume of runoff in a catchment. He further argued that the applicability of Horton's theory is topographically limited because in areas where soil is highly permeable and hydraulic conductivity is low, most of the stormflow discharge from the catchment can be from the subsurface flow. Hewlett (1961) cited in Burt (1989) also claims that runoff will take place as and when the soil profile has reached its saturation phase. Dunne (1978) cited in Burt (1989) went on to widen the spectrum and asserted that runoff generation is influenced by a combination of soil properties, climatic conditions, and the topographical characteristics of a catchment.

Tsubo et al. (2005) and Bracken and Croke (2007) are all in agreement with the concept of Horton's theory that rainfall intensity is the key to estimating runoff, and adds that the duration of a storm event also plays a significant role in the production of overland flow. The revised universal soil loss equation (RUSLE) is a tool used to estimate the total loss of soil per annum (Wischmeier and Smith, 1978). The tool also includes rainfall intensity as one of the factors that influence sheet and rill erosion through runoff (Le Roux et al., 2008). Morgan (2009) echoes this and further enumerates that rainfall's ability to detach soil particles as it lands on the ground surface is dependent on a combination of factors such as: the rainfall intensity; raindrop velocity, mass, and diameter; and the duration of a rainfall event. High intensity storms with big raindrops are the most erosive even when the duration is low, because they have high kinetic energy and quickly produce runoff which causes soil loss (Le Roux, 2011). This is similar to the rainfall patterns in this current study at Macubeni (Ruliv, 2004).

The detachment and transport of sediment can be detrimental to the fluvial systems, primarily in a dammed catchment. This is largely because the high deposition of sediment in rivers and dams reduces their water holding capacity (Le Roux et al. 2013). The ecosystem health of a water body such as a river is thus negatively affected by sediment build up, because the silt in the water: reduces the total amount of sunlight that can penetrate into the water due to high turbidity; reduces primary productivity in the habitat; affects the fish species diversity; and increases downstream flooding (Dalu et al., 2013; Le Roux et al., 2013). This means the water security for the local communities is also compromised, with the reduced water capacity and water quality. Such implications also prevail in Macubeni as the local dam silts up from catchment sedimentation (Riedel and Terblanche, 2009). In addition to effects on livelihoods, Tourism (2006) as cited in Seutloali et al. (2017) reported that the siltation of water reservoirs due to soil erosion also adds burden to the state economy as the water treatment costs increase by close to R2 million annually (Seutloali et al., 2017).

2.2.2 Catchment topography effect on runoff

Topography can in many ways be a major influence on the runoff generated in a catchment. Small catchments are especially sensitive to the scale and slope of the area (Laker, 2004; Yair and Raz-Yassif, 2004) due to the effect that those elements have on the response and discharge volume after rainfall (Hayes and Young, 2006). Yair and Raz-Yassif (2004) also found that the length of slope of a catchment is positively related to the sediment deposition rate as the kinetic energy of the water increases (Laker, 2004).

Moreover, topography is a crucial aspect in the hydrological connectivity level in a catchment. Bracken and Croke (2007) define hydrological connectivity as the process of surface water generating catchment runoff response as it flows and connects from one part of the landscape to the other. Bracken and Croke (2007) highlighted that this continuous flow of rainwater into channels from hillslopes requires rainfall intensity and duration to be high enough to vanquish transmission losses, thus minimising dysconnectivity. The high hydrological connectivity is often observed in hilly landscapes because there is high runoff velocity and erosive power due to the slope angle (Alatorre et al., 2012), which results in the formation of gullies (Valentin et al., 2005). Moreover, Le Roux and Van Der Waal (2020) highlighted that the situation can be worsened if the soil properties in an area make it prone to severe soil erosion, such as in dispersive soils. These soils have low infiltration capacity, poor hydraulic conductivity and high sodium concentration, making them lose their structure when in contact with water (Le Roux and Van Der Waal, 2020).

Correspondingly, Peters (1994) affirmed that drainage networks in a catchment play a huge role in the significance of overland flow that takes place in the area. He revealed that pipe flows and ephemeral streams are some of the natural drainage networks that one finds in a catchment system and that play a pivotal role in inducing runoff and carrying high sediment loads. Leopold and Miller (1956) defined ephemeral streams as those streams which are often found in arid regions, smaller and shorter than perennial, and only flowing as a response to storm events. Some of these ephemeral streams are in fact artificial, such as footpaths from community members or livestock. Roads are also part of the artificial drainage network system that aid in the concentrated flow of water into other channels during rainfall events, thus increasing the soil erosion rate (Valentin et al., 2005).

2.2.3 Land use change

Human activities on the landscape have overtime led to the degradation of land globally, and have been negatively affecting the key systems of the Earth's function (Lambin et al., 2001, 2003). Such systems include biodiversity, climate change, soil quality and general ecosystem services (Lambin et al., 2001). This in turn influences how vulnerable people are to changes in climate and socio-economies (Lambin et al., 2003; UNCCD, 1994). Land use changes had already been identified as having an influence on the climatic conditions in different regions by the mid-1970s, by altering the surface albedo (Lambin et al., 2003). The increase in land use changes during the 1980s further revealed that the global climate through carbon cycles is negatively affected as the terrestrial ecosystems which act as carbon sinks are being destroyed (Lambin et al., 2003). It has been estimated that since 1850, about 6 million km^2 of forests and 4.7 million km^2 of grasslands have been converted into crop lands globally (Lambin et al., 2001).

Scholes (2009) stated that the land degradation drivers in Southern Africa have been mostly due to human-induced factors, rather than the natural physical factors such as topography, vegetation and climate change. The former Transkei for instance, had a dramatic population increase over the twentieth century, leading to high deforestation levels caused by people (Valentin et al., 2005). Hoffman and Todd (2000) already identified the Eastern Cape and KwaZulu as the most degraded landscapes in the country. This is especially true for communal lands rather than commercial areas, where soil and veld degradation are used as indicators (Hoffman and Todd, 2000). Even so, Hoffman and Todd (2000) also argue that the biophysical and climatic conditions of a catchment remain as some of the key players in the influence of land degradation.

Overgrazing is also an issue that has been widely discussed as a major land degradation influence in Southern Africa (Hoffman and Ashwell, 2001). However, Behnke et al. (1993) in Lambin et al. (2001) argued that the changes in rangelands' productivity in arid tropical and subtropical regions are mostly driven by biophysical factors such as rainfall variability, and that stocking rates have little effect on the long-term time scale. On the other hand, tropical and subtropical zones that are not arid are seen to be driven by a combination of biophysical and human factors (Lambin et al., 2001). Valentin et al. (2005) maintain that overgrazing is detrimental because it enables the depletion of organic matter from the topsoil; this disturbs the soil structure and makes it susceptible to high soil erodibility rates during runoff. The behaviour of livestock alongside its total population in the area can also be attributed to rates of degradation in a catchment. This is due to livestock creating a web of paths on the soil surface within the catchment and adding to the landscape connectivity, thus compacting the soil and increasing runoff potential (Valentin et al., 2005).

Molina et al. (2009) further revealed that overgrazed and abandoned agricultural lands are responsible for a vast majority of the gully formation on the land and the disturbance of the hydrological regime. Gullies also promote catchment hydrological connectivity, which further exacerbates soil erosion. Nevertheless, Tamene et al. (2017) concurred with Wei et al. (2007) that crop lands take the lead in the high rates of surface overland flow compared to other land use types (i.e. woodlands and pastureland).

2.2.4 Vegetation cover

Land use systems within a catchment also affects vegetation cover. For instance, Wigley et al. (2009) found that in Hluhluwe (in the Kwazulu-Natal (KZN) province of SA), the land use change has negatively affected vegetation cover for the past 70 years. The changes included going from grass cover to more woody species (shrubs and trees), and a decline in forested areas, where 12% of it was converted to cultivated lands. This plays a huge role in determining the rate of soil loss that occurs in a catchment during a storm event (Heidarnejad et al., 2006). The more vegetation cover present on the soil surface, the more runoff velocity reduction that takes place (Bunning et al., 2011). Therefore, if deforestation levels in the area are high, the runoff velocity is increased as there is too little or no vegetation to intercept the flow. The reduction in runoff velocity causes the flow to lose some of its erosive power and increases the infiltration rate, thereby reducing the total erosion that takes place on the soil surface (Laker, 2004). In addition to the vegetation cover, Chamizo et al. (2017) elaborate that the soil loss can also be reduced by the thin layer called biocrust on the surface of bare ground, which is made up of various microorganisms, mosses, cyanobacteria, and lichens. This crust is a few millimetres thick and binds soil together, making its structurally stronger and resistant to erosion. These are all therefore important considerations for land cover.

2.3. Soil erosion dynamics on the South African landscape

As far back as the 1880s, South Africa was already publishing reports on land degradation observed on the landscape, particularly in the Ciskei region, and even then attributed it to overgrazing and soil erosion (Beinart, 2008). With communal lands being at the forefront of progressing land degradation, the Transkei was also reported to be exhibiting signs of degradation by the 1920s (Beinart, 2008).

Moreover, with more than 1Mha of land subjected to high erosion rates in South Africa, soil loss is estimated to be 8 to 30 times faster than soil formation (Seutloali et al. 2017). Although this may be true, the erosion rates are not uniform in the different areas of the country's landscape (Meadows and Hoffman, 2002). Some areas have higher/lower erosion rates than others due to the varying topographical characteristics, socio-economic factors and weather patterns (Le Roux et al., 2008). For instance, in communal areas, there is a lack of livestock management on grazing lands plus an erodible nature of soils, thereby resulting in higher degradation levels (Blair et al., 2018). As a result, communal lands in the Eastern Cape, Kwa-Zulu Natal and Limpopo are said to be the most severely affected by land degradation (Hoffman and Ashwell, 2001; Le Roux et al., 2008). This is also true for the area in this current study (Macubeni), as it is situated in the Eastern Cape and described as one of the most severely degraded areas in the country (Hoffman and Todd, 2000), which makes it one of the focus areas for several land rehabilitation projects. Land rehabilitation refers to the actions which are taken to improve the ecosystem health and its ability to provide goods and services (Sanz et al., 2017).

Jury and Levy (1993) highlighted the 1970s as a period in the Eastern Cape when extreme rainfall events and floods occurred. It was during this period when an increase in the severity of erosional features such as gullies was eminent (Kakembo and Rowntree, 2003).

The apartheid system in South Africa created several socio-economically and biophysically disunited communities in the country, based on racial identities (Meadows and Hoffman, 2002). This system enabled the white minority to be the most privileged group and be given preference in ownership of productive lands with optimum climatic and geological conditions for commercial farming (Meadows and Hoffman, 2002). The occurrence and extent of land degradation in communal lands is therefore associated with the historical land tenure setup of high population density on smaller plots of land with lower land productivity (Meadows and Hoffman, 2002). Similarly, in Botswana, Mulale et al.

(2014) found that human habitation and overgrazing are not the only factors that contribute to the significant soil erosion that exists in the country. They concluded that historical legislation and unsustainable land use policy implementations have led to severe land degradation in communal lands.

Contrary to the consensus, several studies (Abule et al., 2005; Kassahun et al., 2008; Solomon et al., 2007) have come forth echoing that the communal land management systems historically used by indigenous people of the area, are in fact more compatible with the environment than believed to be. Hence, Waudby et al. (2012) concluded that to achieve sustainable development, it is vital for the implementation of resource management programmes to place the community at the forefront of the operation. They added that this enables the community to take leadership roles in the participation of the project and thus be involved in the decision-making for their own land and find value in the sustainable development of their space. This has been practiced in communal lands such as those in the Limpopo province in South Africa, where a fodder flow programme for livestock feed was developed using the knowledge of the local farmers (Beyene et al., 2014). The same bottom-up approach has also been applied by the GEF5 SLM project in this project's study area.

2.4. Gully erosion processes

Historical research has shown a correspondence between periods of major gullies and erratic rainfall event (Valentin et al., 2005) as a part of land degradation. This is especially evident in areas where the mean annual rainfall is below 450 mm, because whenever high-volume precipitation occurs, the erosion rate is increased (Morgan, 2009). When overland flow slightly increases vertical erosion on the soil surface, erosional features such as rills form (Pretorius, 2016).The rills develop into gullies if the erosion persists and makes the incision bigger by creating a waterfall and plunge pool that undermines the gully backwall (Bull and Kirkby, 1997). Therefore, gullies are bigger incisions on the ground which are often found on lower gradients of the drainage area (Mararakanye and Sumner, 2017) and vary in sizes (from about 0.5 m to tens of meters) and shapes (some V-shaped, some U-shaped).

With the risk of sheet erosion argued to increase even further on cultivated land (Seutloali et al., 2017) due to the soil structure being disturbed and soil exposed to rainfall erosive effects (Huchzermeyer et al., 2018), the formation of gullies is almost inevitable. Gully erosion occurs through a process where a concentrated flow of surface or subsurface water forms incised channels (Mararakanye and Le Roux, 2012). As highlighted by Ravi et al. (2010) one of the main sources of sediment is gullies, and gullies are one of the biggest forms of land degradation in South Africa. Although there is a wealth of research on gully systems, little has been done in conjunction with crop lands. Hence this study aims to assess the level of degradation in cultivated and previously cultivated lands characterised by the presence of gullies (amongst other indicators i.e. vegetation cover).

2.4.1 Drivers of gully formation

Recognising the detriments of erosion, Wischmeier and Smith (1978) developed what is called a Universal Soil Loss Equation (USLE) aimed at estimating soil erosion on cultivated fields. This equation consists of the following five interactive factors of erosion: rainfall erosivity, soil erodibility, slope length and steepness, crop management, and support practice. The combined effects of these factors have since been widely used in assessing soil erosion. Valentin et al. (2005) identified the parent material-soil association, land use-cover interactions and topographical variables as some of the major contributing factors in gully formation.

Moreover, Mararakanye and Roux (2012) conducted a study where they used SPOT 5 imagery at a scale of 1:10,000 within a geographic information system to create a gully location map for SA. They found that the extent of gully erosion in the Eastern Cape is about 161 517 ha. It is observed that gullies tend to develop on erodible soils derived from weak parent materials, poor vegetation cover and gentle foot slopes in zones of saturation along drainage paths (Le Roux and Sumner, 2012; Mararakanye and Le Roux, 2012). Furthermore, the assessment of factors contributing to gully erosion is important for effectively controlling gullies (Mararakanye and Le Roux, 2012) and implementing site specific interventions (Le Roux and Sumner, 2012).

Mararakanye and Sumner (2017) assessed the influence of factors contributing to gully erosion from two catchments in the Mpumalanga province of South Africa. They identified the geology, land use, rainfall, soil type and vegetation cover as the contributing factors. Their methods included using the Revised Universal Soil Loss Equation (RUSLE) model for rainfall erosivity and satellite imagery and Normalized Difference Vegetation Index (NDVI) for vegetation cover.

2.4.2 Gullies as sediment sources

Like several authors in this field, Ravi et al. (2010) and Le Roux et al. (2013) agree that the sediments sourced from gullies are transported and deposited into water bodies within the catchment. This reduces the capacity of reservoirs and negatively affects water use and ecosystem health due to high siltation rates. As mentioned before, siltation of water resources is one of many detrimental effects of soil erosion and one of the biggest challenges faced by communities in dammed catchments. In addition to that, other negative impacts of gullies are: separation of villages, loss of property, loss of soil fertility, and injuries to children and livestock (Hassen and Bantider, 2020). In addition, several studies (Mararakanye and Sumner (2017) in South Africa , Tamene et al. (2017) in Ethopia and Zabihi et al. (2018) in Iran) agree that the occurrence of gullies is higher on hillslopes steeper than 4.5°, overgrazed areas, shallow soils, and cultivated land.

2.5. The dynamics of abandoned crop fields

Studies show that different communities around the world continue to abandon their crop lands (Cramer et al., 2008; Li and Li, 2017; Ramankutty and Foley, 1999). By 1999, it was already estimated that 1.5 million km^2 of forest areas and 0.5 million km^2 grasslands that were converted into crop lands since 1850 had been abandoned (Ramankutty and Foley, 1999). The situation appears to be dire within sub-Saharan Africa (Bryceson and Laan, 1994; Shackleton et al., 2013). Yet, it is a land use change aspect which is still understudied. Blair et al. (2018) concur with this argument in their study about crop land abandonment in South Africa where Transkei was found to have an abandonment rate of 0.13% per year. They highlight that natural and socio-economic aspects of agricultural activities are interconnected at various scales, which often creates difficulties in defining abandoned fields. For instance, farmland clearing or interrupted and short periods of crop farming due to drought or temporary lack of labour may be confused with abandoned land (Hebinck et al., 2018; Pointereau et al., 2008) It must however be noted that in this particular study, the terms abandoned fields or previously cultivated fields as defined by Blair et al. (2018), refer to the piece of land on which all crop agricultural activities have ceased.

2.5.1 What happens on abandoned crop lands?

Land cultivation, with zero tillage technique being the exception, poses a higher risk of soil erosion (Huchzermeyer et al. 2018). This is due to the disturbance in soil structure and soil being exposed to rainfall erosive effects (Huchzermeyer et al. 2018). Kakembo and Rowntree (2003) found that severe and irreversible erosion resulted in the loss of about 27% of the cultivated lands in communal areas by 1988. One of the ways in which this loss of cultivated lands occurs is that when runoff flows on the destabilised soils, it strip off the top organic content and leaves it unproductive, thus abandoned (Le Roux, 2011; Parwada and Van Tol, 2016).

Studies such as de la Hey and Beinart (2017) and Jewitt et al. (2015) have observed that the abandonment of crop agriculture lands has been a growing trend in South Africa. These abandoned fields become erosion hotspots as they are left exposed to erosion with no vegetation cover to stabilise the soil structure and provide runoff effect reduction (Huchzermeyer et al, 2018). If no land rehabilitation measures are put in place, the soil in these fields is left degraded and highly prone to high runoff and extreme soil erosion (Kakembo and Rowntree, 2003). This further inhibits revegetation, especially if the area also suffers from drought (Kakembo and Rowntree, 2003).

Therefore, gully formation is triggered (Valentin et al., 2005), which is one of the biggest land degradation challenges faced on the South African landscape (Ravi et al. 2010).

Furthermore, in working towards understanding the dynamics of crop field abandonment, Blair et al. (2018) used a mixed approach method to investigate the rates of crop field abandonment in four former Apartheid homelands. This included the use of remotely sensed imagery to assess the landcover changes over time. Similarly, this study also makes use of satellite images to further assess the vegetation vigour on different statuses of crop fields in the study area.

2.5.2 Drivers of crop field abandonment

Looking beyond the natural processes that occur on abandoned fields, one finds that there is a wide range of reasons across countries around the world for the abandonment of fields (Blair et al. 2018; Kakembo and Rowntree, 2003). These generally include factors such as: lack of draught power (i.e., animals used for ploughing fields), rainfall variability and droughts, more modernized youth shifting away from the agrarian lifestyle, and land overuse (Blair et al. 2018; Kakembo and Rowntree, 2003). These factors along with how they interact with each other, are discussed further in Chapter 6. In Southern Africa, there has been an overall increase in the degree and extent of abandoned fields (Hebinck et al., 2018; Shackleton and Luckert, 2015). Hebinck et al. (2018) argue that this is due to the overall strengthening rural-urban connections, yet Shackleton and Luckert (2015) attribute it to globalization and modernization. Several studies (Hajdu, 2005; Hebinck et al., 2018; Shackleton et al., 2013; Shackleton and Luckert, 2015; Shackleton, 2018) indicate that the arable land that is farmed in rural areas has decreased, while increasing the number of smaller home gardens and reducing livestock ownership. Moreover, some studies suggest that increasingly diversified household incomes and activities (Twyman et al., 2004), and changes to ‘agrarian’ identities (Hebinck et al., 2018) also play a role in increasing the number of abandoned fields. In essence, this range of factors influencing the abandonment of cultivated land illustrates the complexity of the system and thus the need to use a Systems Thinking approach, as done so in this study.

Shackleton and Luckert (2015) argue in a study conducted in the Eastern Cape that there are short term ‘shocks’ such as the unemployment or loss of a bread winner through death which also drive crop field abandonment. Other factors include the systemic effects of HIV/AIDS, altered rural demographics and rural values, erosion of social and cultural capital, and low education levels (Shackleton and Luckert, 2015). Furthermore, it has been observed that in most rural areas, social grants have created a high level of dependency on governmental assistance, thus promoting the unwillingness of community members to partake in agrarian activities, and further increasing their vulnerability to poverty (Shackleton and Luckert, 2015).

Moreover, in a survey conducted in the former Apartheid Transkei and KwaZulu homelands, Blair et al. (2018) found that most people who ceased farming attributed it to reasons such as: declined soil quality, lack of access to irrigation water, unpredictability of the weather, having alternative income, required input in costs and labour exceeding output benefits, increased cattle death rate, youth having little to no interest in farming, lack of farming equipment, and lack of labour. Furthermore, farmers stated that for them to be able to resume their farming activities, they would need to have financial credit support, access to more affordable farming methods, agricultural training programs and governmental support through the provision of equipment and grants (Blair et al. 2018).

Additionally, due to the historical socio-political inequalities created by the government during the Apartheid era, the issue of crop fields abandonment in South Africa becomes a complex one (Blair et al., 2018). Under this government, land tenure rights were based on race, and black people were forced into designated densely populated areas called “homelands” through the Natives Land Act of 1913 (Kirsten et al., 1994; Ngidi, 2014). This resulted in increased human and livestock pressures (Shackleton and Gambiza, 2008).

Hebinck and Lent (2007) concurs with Andrew and Fox (2004) that the abandonment rate of crop fields in South Africa increased during the peak of the Betterment Planning schemes back in the 1970s and 1980s. Betterment Planning was a form of rural development programme that the South African government initiated in 1936 in an attempt to increase agricultural sustainability and conserve the environment (Andrew and Fox, 2004). This was implemented by demarcating certain areas in the rural homelands as arable land, residential or grazing area (McAllister, 1991). As a result, a lot of people were relocated from their widely spread homesteads into the new nuclear village type of “residential area”, while also declaring some of their land as unsuitable for agriculture, thus halting farming on it (McAllister, 1991). Although this was aimed at bettering the lives of the rural communities whilst conserving the environment, several studies revealed that the planning had significant negative socio-economic effects on the people (Bank, 2005; Fay, 2003; Hebinck, P.; van Averbeke, 2007; McAllister, 1991; Shackleton et al., 2013). The consequences included reduced arable land and more distance between dwelling areas and people’s crop fields (Andrew and Fox, 2004). Ultimately, agricultural investment was since disincentivised due to the increased time, effort and financial inputs required to maintain the crop fields (Andrew and Fox, 2004).

2.5.3 Implications of abandoned fields

The impacts of abandoned fields from an ecological perspective broadly include the alteration of ecosystem services, habitats, biodiversity, hydrological regimes, carbon sequestration and soil fertility (Munroe et al., 2013).

2.5.3.1 Changes in soil quality

As mentioned before, cultivation (except for zero tillage process) creates a disturbed soil structure and remains that way for a long time even after all agricultural activities have been halted (Huchzermeyer et al., 2018) as it takes some time for it to recover (Harvey, 2001) after the sediment yield has peaked and normalised (Fryirs and Brierley, 1999; López-vicente et al., 2013). Therefore, the sediment yield increases and abandoned fields become erosion hotspots, which increases gully formation (Huchzermeyer et al. 2018; Kakembo and Rowntree, 2003). The high sediment yield from abandoned fields leads to sedimentation and siltation of reservoirs, which as stated earlier, is a major problem in dammed catchments due to the water security threat it poses on local communities, much like the one targeted in this study. Another effect of having abandoned fields is the increased susceptibility to invasive plant species (Cramer et al., 2008). Moreover, Beyene et al. (2014), Gxasheka et al. (2019) and Molepo et al. (2017) all echoed that bush encroachment by invasive and/or expansive species in a catchment can lead to a decrease in soil nutrients content and distribution, therefore a declining soil quality, less grass cover and ultimately even more encroachment as those species thrive on degraded land. Scholes (2009) added that woody species have a strong negative effect on the successful growth of grass. This creates a negative reinforcing effect on the ecosystem, which is clearly visualised in the qualitative model created in Chapter 6.

2.5.3.2 Decline in land productivity

Shrivastava and Kumar (2015) state that unsustainable agricultural practices such as inappropriate cultivation and irrigation practices promote poor drainage, which leads to increased infiltration and a higher water table level. The raised water table increases the concentration of salt content in the soil as evaporation and evapotranspiration takes place, thus resulting in salinization, reduced land productivity, and even more cultivation and irrigation in an attempt to increase land productivity. Again, this creates a reinforcing effect leading to more cultivated land being abandoned. Lastly, Pienaar and Von Fintel (2013) found that due to the strong presence of agricultural disengagement and how the national interventions in South Africa have failed to halt this trend, the number of previously cultivated lands will continue to increase. This puts emphasis on the importance of SLM interventions.

2.5.3.3 Changes in socio-economic factors

Navarro and Pereira (2015) argue that synergies and feedbacks are created from the interaction of socio-economic and biophysical factors within and across various scales. This concurs with the general concept of systems mapping, which is that the elements involved in a system interact in a non-linear fashion. With that said, there are several ways in which the abandonment of crop lands negatively affect communities. These include the loss of the traditional landscape (Munroe et al., 2013), and deterioration of lifestyle, cultural heritage and identity and values (Daugstad et al., 2006). At a regional scale, the supply to markets and agricultural production associated support services are reduced. Furthermore, the pressure on urban centres increases due to the displacement of rural livelihoods (Munroe et al., 2013).

The reasons behind crop field abandonment are also just as context specific as their effects on the community and environment (Blair et al., 2018). The abandonment of crop fields has been observed to not only occur in the less productive or inaccessible areas, but also in those agricultural lands that are more productive and accessible (Hatna and Bakker, 2011; Hinojosa et al., 2016; MacDonald et al., 2000; Vinogradovs et al., 2018). Moreover, socio-economic consequences of crop land abandonment in rural areas include, at household level, the reduction in self-provisioning capacity and income (Shackleton et al., 2001), diminished dietary diversity, increased food insecurity, vulnerability and poverty (Daugstad et al., 2006).

2.5.3.4 Impacts of land abandonment on ecological factors

The ecological impacts of abandoning agricultural land have been widely researched in places such as Western Europe (e.g. Navarro and Pereira, 2015; Verburg and Overmars, 2009); however, the same efforts of researching ecological impacts have not been applied in developing countries, although this is gradually increasing (Cava et al., 2018; Laue and Arima, 2016; Shackleton et al., 2013). Cramer et al. (2008) argue that the limitations of such research on the ecological aspect, is that the ripple effect of crop land abandonment is highly dependent on the local pre-existing biotic and abiotic context, and the historical agricultural activity of that geographical region. In some areas, crop field abandonment is influenced by climatic extremes such as floods and droughts, or edaphic factors such as erodibility, soil fertility and soil depth, which makes the land prone to gully erosion (Benayas et al., 2007).

2.6. Sustainable land management practices

The ELD Initiative (2015) argued that if soil erosion is to be managed, about 280 million tons of cereal crop loss per year can be prevented. In the same breath, as a response to the evident land degradation and desertification impacts, sustainable land management practices (SLM) have been acknowledged and widely promoted in many countries across the globe (Schwilch et al, 2014). SLM practices are defined as the sustainable use of land resources, such as water, soil, plants and animals, for human needs, while simultaneously ensuring the longevity of their environmental functions (Liniger et al., 1999). This enables adaptation and resilience of ecosystems in a world where there is a constant change in natural conditions (i.e. climate change) and in socio-economic (i.e. migration and global markets) spaces (Liniger et al., 1999), thus supporting Land Degradation Neutrality and Sustainable Development Goals (SDG). Studies have also shown that an investment in SLM practices (which reduce the loss of productive land) right now and integrating them into policy and planning is beneficial and cost effective because land degradation has been predicted to incur huge costs in the future (ELD Initiative, 2015; IPBES, 2018).

The World Overview of Conservation Approaches and Technologies (WOCAT) is a platform for promoting SLM practices globally (Liniger et al., 1999; Sanz et al., 2017). WOCAT describes SLM technologies as the physical agronomic, vegetative, structural, or management measure applied in the field that controls land degradation and enhances productivity (Sanz et al., 2017). An SLM approach on the other hand is defined as the ways and means used to promote and implement a given SLM technology group.

Many studies (ELD Initiative & UNEP, 2015; Mulale et al., 2014; Sanz et al., 2017; Schwilch et al., 2014) have published the use of different SLM activities; however, there is a lack of information in the literature about the effectiveness of these implementations. It is for this reason that the effectiveness of SLM activities is set as one of the objectives in the current study. Schwilch et al. (2014) advise that the assessment of SLM effectiveness within a socio-ecosystem is to be guided by principles of monitoring and evaluation at different spatial and temporal scales, and the use of an appropriate indicator of progress.

2.6.1 Overarching SLM technologies

The UNCCD Science Policy Interface identified fourteen overaching SLM technology groups that have the potential to mitigate land degradation (Sanz et al., 2017) as displayed in Figure 2.1. Moreover, the most common SLM practices that are implemented to address land degradation are related to preventing soil erosion and soil deterioration and improving productivity and biodiversity (Sanz et al., 2017). These include the following SLM technology groups: soil erosion control, integrated soil fertility management, minimum soil disturbance by tillage vegetation management, sustainable irrigation systems, drainage and water harvesting. SLM activities often mitigate soil erosion through reducing surface runoff by structural or vegetative barriers and/or by increasing soil cover (Sanz et al., 2017). Hence this study focuses on the SLM practices for soil erosion control. As echoed by Schwilch et al. (2014), there is a need for more research to reinforce expert assessments of SLM impacts and provide the necessary motivation and rationale for investment in SLM.

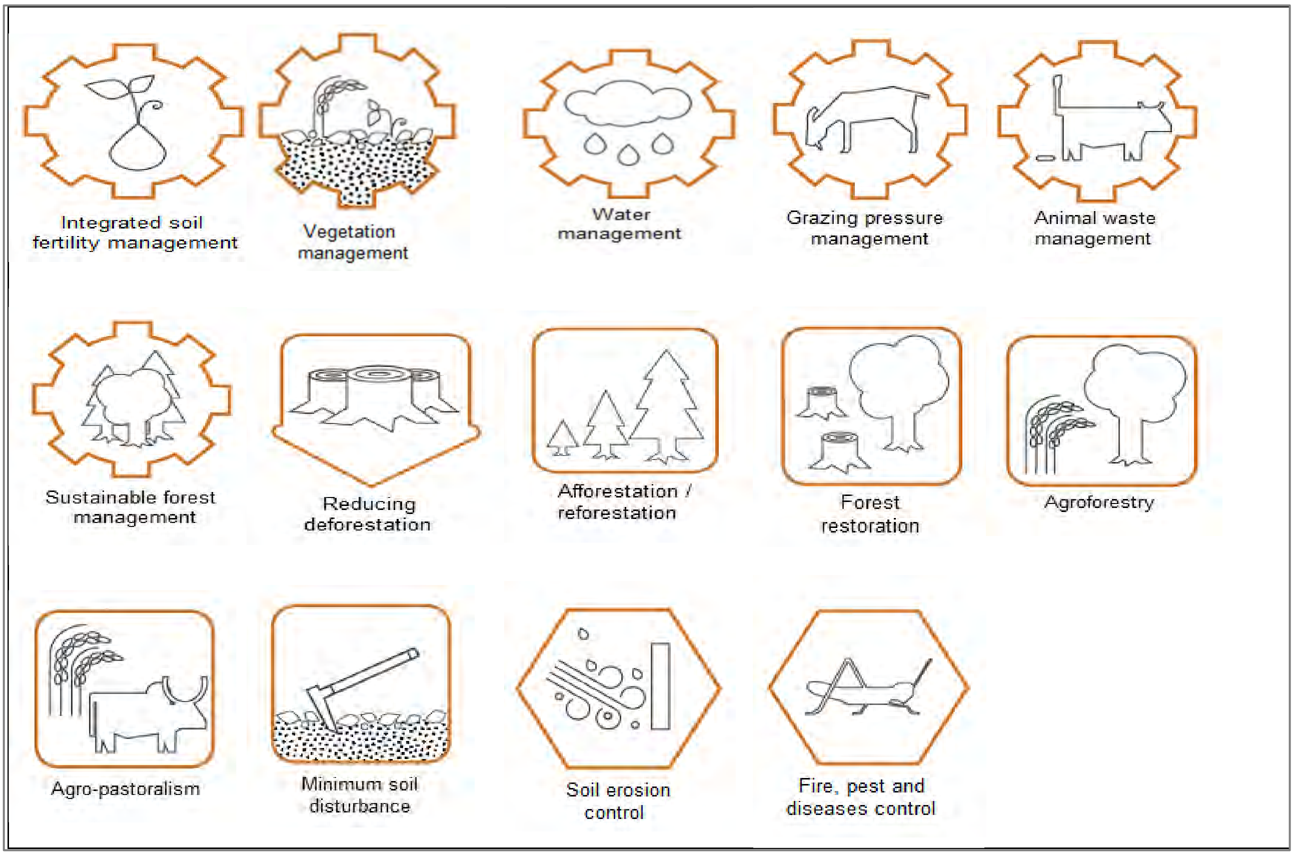


Figure 2.1: SLM technology groups identified by UNCCD Science Policy Interface (WOCAT, n.d.)

2.6.2 Soil erosion control strategies

Soil erosion control practices can be applied in numerous ways for different requirements in a catchment. Sanz et al. (2017) highlighted that most of the approaches for soil erosion control fall into one of three measures i) vegetative measures, such as windbreaks and live hedges; ii) structural measures, such as soil bunds and stone walls; and iii) combined or integrated measures, such as riverbank stabilization. Examples of best practices in soil erosion control, as reported by WOCAT (n.d.), include the following:

- Stone lines: a barrier constructed with stones along the contours for runoff velocity reduction, and enhanced water infiltration. It blocks and settles down the sediments transported from the upper slopes. This practice is often used as a rehabilitation method on eroded and abandoned land.
- Rock wall terracing: the use of stones or rocks to create a pile along contour lines to mitigate soil erosion in hilly areas.
- Natural vegetative strips: strips of land are marked out on the contour and left un-ploughed to form permanent, cross-slope barriers of naturally established grasses and herbs.
- Integrated gully treatment: i.e. stone and wooden check dams, cut-off drains and reforestation in sediment traps.
- Soil bund: a structural measure built along the contours with embankment of soil or stones, and stabilised with vegetative matter, such as grass and fodder trees. These structures enable high infiltration rates as the water runoff velocity is reduced.

SLM practices are similar across different landscapes. However, in a study set to review various SLM practices in the Sahelian countries in Africa and strategies for up-scaling land restoration, Maisharou et al. (2015) warns that there is no one-size-fits-all solution for the application of SLM practices and techniques. They argue that to determine the most suitable practices and techniques for land rehabilitation, the target area's agro-ecological conditions (i.e. topography, type of degradation, rainfall, vegetation cover and soil properties), socio-economic and cultural practices need to be taken into consideration. Nonetheless (Maisharou et al., 2015) mention that often the failure of farmers to take the initiative hinders the up-scaling of SLM practices. This is not attributed to lack of knowledge but lack of incentives. Furthermore, soil erosion control measures through SLM practices are quite essential as this enables smart management of dams, thus avoiding a shortened lifespan (Brambilla et al. 2015). The Macubeni dam in this study is indicative of this as it is highly silted due to decades of uncontrolled sedimentation in the catchment (Riedel and Terblanche, 2009).

2.7. System dynamics tool

Sterman (2001) defined system dynamics (SD) as a very efficient computer-aided tool used to understand the different interactions within a complex system over time. This is inclusive of both the positive and the negative feedbacks in the system, along with time delays. It is especially applicable when one part cannot explain the behaviour of the entire system as it is nonlinear. In the same breath, Holmström (2017) states that the causality function of the SD method remains at the core of this methodology. He further echoes that the method has an ability to compute simultaneous interactions which a spreadsheet would fail to calculate, thus enabling it to solve mutual causation problems.

Moreover, according to Sterman (2001), people generally have very limited mental models which are unreliable and inconsistent. He highlighted that we tend to make decisions based on short-term visions that lack an understanding of the complexity of the problem at hand and the impact of our actions. As a result, the ripple effect of our actions ends up affecting us in the long run. Hence in this study, to overcome the parochial mental model, a conceptual model through causal loop diagrams is used to provide a theoretical simulation of the impact of SLM practices and facilitate and promote holistic land management that is inclusive of socio-cultural, environmental, and economic aspects.

Studies such as that by Holmström (2017) concur with Sterman (2001) on there being numerous advantages that come with using SD model simulation. These include being able to visualise the system behaviour, thus aiding understanding, and being able to identify emergent properties which may not have become apparent in a linear process. However, like any method, SD model simulation also has its shortfalls, one being that the simulation may not 100% accurately represent the actual scenario, thus overestimating or underestimating the results. Secondly, validation of these models requires a large set of data to test them thoroughly, thereby posing a challenge in that aspect (Sterman, 2001).

2.7.1 Historical use of system dynamics

As mentioned previously, the use of system dynamics has been increasingly promoted within various disciplines. In India, system dynamics was used during an environmental impact assessment (EIA) process, to estimate the feasibility of alternative approaches for pollution control in a coalfield (Vizayakumar and Mohapatra, 1992). Sudhir et al. (1997) developed a system dynamics model to capture the complex nature of the different components involved in a sustainable urban solid waste management in India. They presented potential outcomes that would exist based on different policy alternatives. A system dynamics model in Vermont was utilised to analyse the spatial and temporal changes in the mechanisms of recharge and flow in a fractured bedrock aquifer (Abbott and Stanley, 1999).

Furthermore, Yeh et al. (2006) used system dynamics in combination with GIS and the universal soil loss equation (USLE) to estimate nutrient production, soil erosion and sediment yield in the Keelung Watershed in Taiwan. They reiterated that some of the important key factors of system dynamics tools include the ability to trace and demonstrate the interdependency between different variables and parameters. Cakula et al. (2012) also applied this tool in combination with the revised universal soil loss equation (RUSLE) to highlight various factors that play the most significant roles in soil erosion.

In 2015, systems mapping was employed in a case study conducted in Pakistan where stakeholders engaged in managing the soil salinity in the basin (Inam et al., 2015). In the Tsitsa River Catchment in South Africa, Itzkin et al. (2021) coupled systems dynamics with community workshops, interviews and literature to understand the social and biophysical drivers of land degradation and how they are interlinked. This was applied to inform the sustainable land management process. Itzkin et al. (2021) identified physical and climatic variables, overgrazing, land cover and land use changes as the key drivers of degradation. These case studies are indicative of how powerful the systems thinking approach can be in solving complex issues and answering different research questions.

2.8. GIS and remote sensing

Another tool used in land degradation analysis is Geographical Information Systems (GIS), which is a very useful computer-based system with tools for processing and creating various types of maps from spatial data on different landscapes for specified goals (Jain and Goel, 2002). Studies such as Fistikoglu and Harmancioglu (2002) have used the Universal Soil Loss Equation (USLE) model in conjunction with remote sensing in GIS to determine the soil loss rates from rainfall-based erosion in Turkey. Jain et al. (2003) made sediment yield assessments from a river using suspended sediment load and empirical relationships, where empirical relationships involving topography and land use were explored through GIS techniques.

In Kenya, Onyando et al. (2005) integrated land and water information systems with GIS to gauge how much sediment is produced from the Perkerra river catchment. Similarly Pandey et al. (2007) investigated degradation-prone areas using the combined effect of GIS and remote sensing so as to enable land rehabilitation priority areas. Jain and Goel (2002) further applied remote sensing through NDVI analysis in combination with GIS techniques to assess vegetation conditions. NDVI measures the balanced-out energy from received versus emitted by plants (Meneses-Tovar, 2011). NDVI can further provide insight on which areas are exhibiting early signs of land degradation, provided the appropriate raster data is inputted (Scanlon et al., 2002; Wessels et al., 2004). The output NDVI values may sometimes be distorted by various factors such as atmospheric conditions, spectral effects, clouds, and soil (Wessels et al., 2004). With the aim of reducing the soil erosion risk at a national South African scale, Le Roux et al. (2008) also used NDVI to estimate the vegetation growth over four years. These studies are illustrative of the value and practicality in applied GIS techniques in soil science, which is also used in this present study as detailed in the following chapters.

Chapter 3. Study area

3.1. Locality and topography

This study is based in an area called Macubeni (31°30'53.92"S; 27°9'53.49"E), which is a tract of communal land in the Emalahleni Local Municipality of the Chris Hani District in the Eastern Cape Province, South Africa (Figure 3.1). Macubeni covers 16 150 ha of land in the upper reaches of the Cacadu river catchment between the Stormberg mountains to the north and the Mount Arthur Range to the south, and flows into the Macubeni dam (Shackleton and Gambiza, 2008). The area has a hilly and mountainous terrain with an altitude ranging between 1300 and 2100 meters above sea level (Shackleton and Gambiza, 2008).

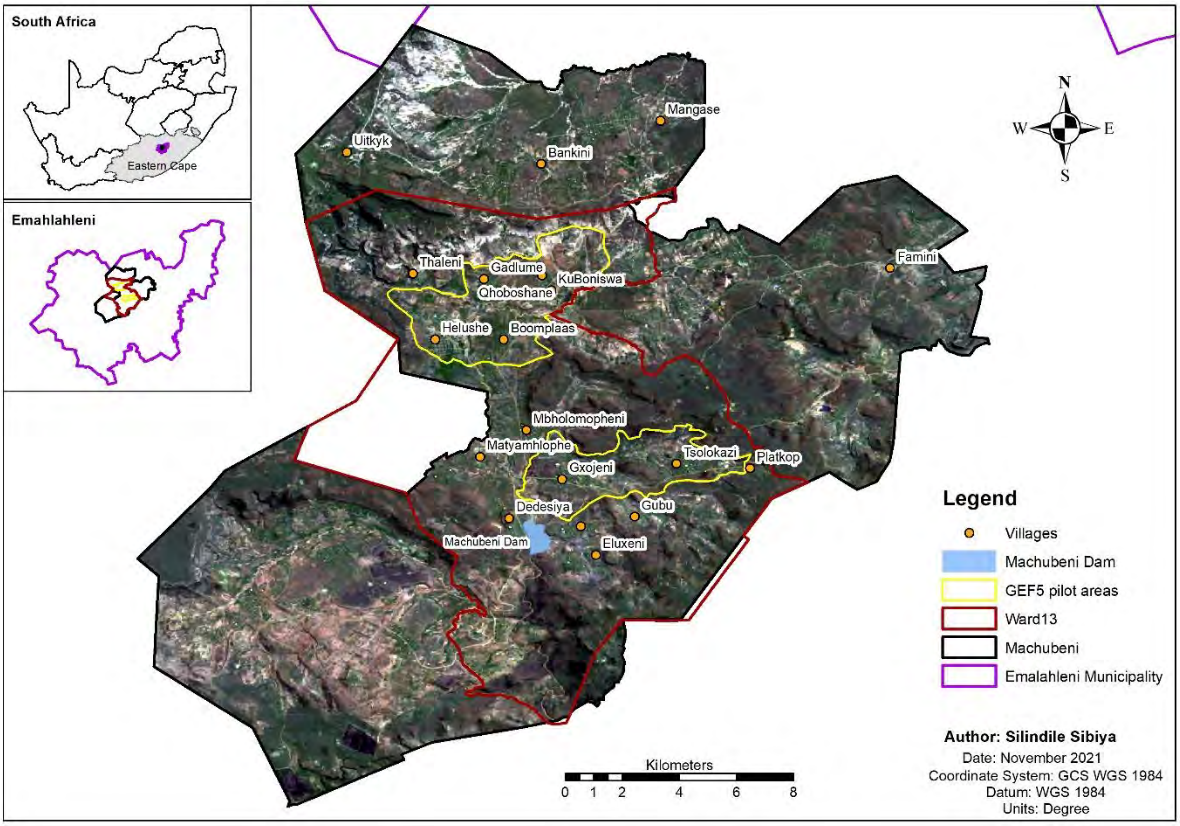


Figure 3.1: Map showing the location of Macubeni communal land (GEF5 SLM Project).

According to StatsSA (2011), the Macubeni communal area is spread across 17 villages which make up a population of 7800 people from 1700 households. Elderly people and young children make up the bigger percentage of the population, and unemployment rates are significantly high (StatsSA, 2011). As a result, the majority of the population is dependent on social grants as their main source of income (StatsSA, 2011). This study only focused on ward 13 of the Macubeni area and used five villages that the GEF5 SLM Project is working with, namely, Boomplaas, Helushe, Qhoboshane, Gxojeni and Platkop as pilot sites.

3.2. Climate and hydrology

Daytime temperatures in this area are typically at an average of 27°C in summer and drop to about 11°C in winter (World Weather, 2021). Furthermore, the catchment receives an average annual rainfall of about 590 mm interchanged with periods of droughts that play a significant role in the water challenges that people are faced with in the area (Shackleton and Gambiza, 2008). More than 70% of the rainfall in the catchment occurs during the summer season, while only 30% of it occurs in winter (Riedel and Terblanche, 2009). Summer rains are often in the form of heavy thunderstorms that have a high soil erosive effect as they reach up to 50mm/hr (Riedel and Terblanche, 2009). The major water source in the catchment is the Cacadu River, which feeds into the Macubeni dam (Fabricius and Cundill, 2010). Figure 3.2 illustrates the river system in the catchment and the Macubeni dam. The dam is currently heavily silted due to the high rate of soil erosion taking place in the catchment. Furthermore, even though the precipitation rates are high in summer, the evaporation rates counteract the water balance because it is higher (2000mm/yr) than the average rainfall (Riedel and Terblanche, 2009). The rainfall patterns in Macubeni are thus not conducive to crop production, and make it imperative for people to employ climate-smart agriculture techniques for better production (Riedel and Terblanche, 2009).

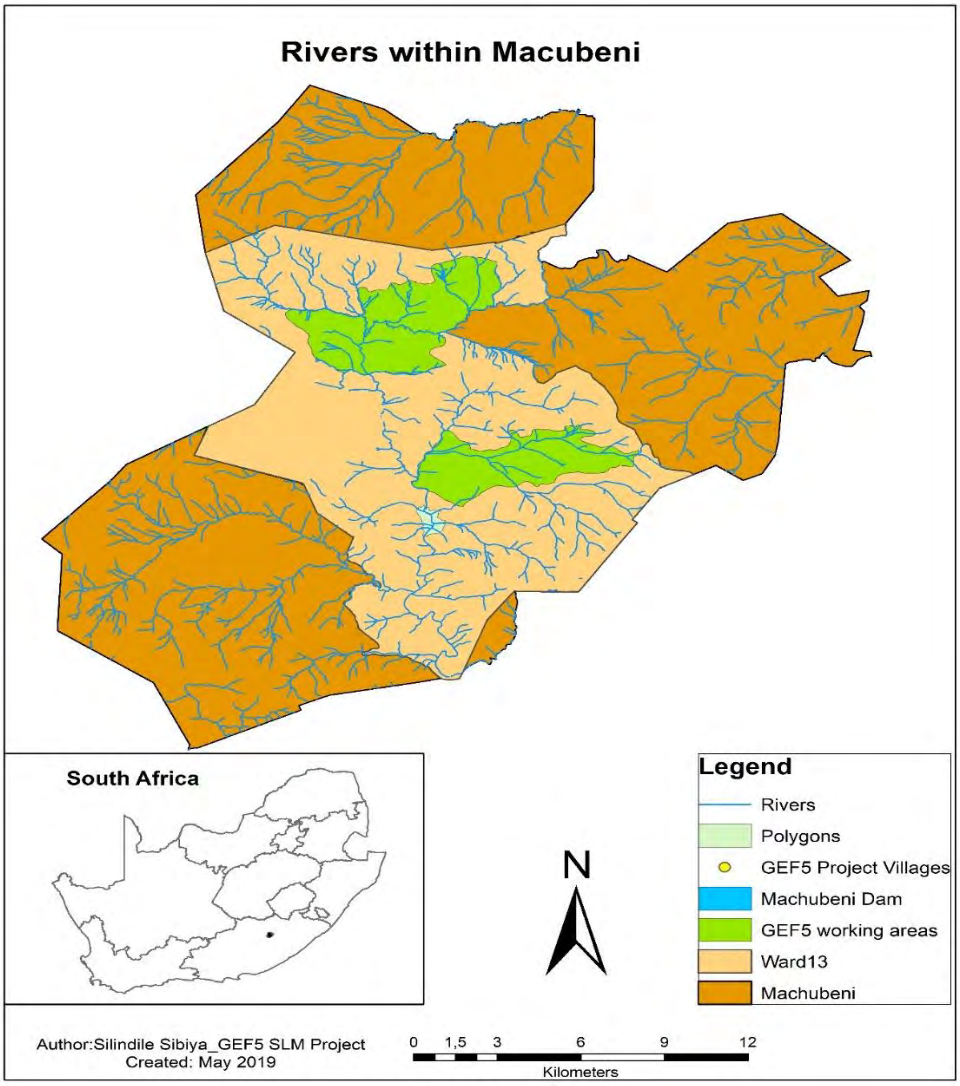


Figure 3.2: Rivers in Macubeni

3.3. Local geology

The underlying geology of the area is comprised mainly of sandstones and mudstones of the argillaceous Karoo Supergroup rocks, and Elliot and Molteno Formations (Shackleton and Gambiza, 2008) as seen in Figure 3.3. Besides the valley bottoms, the area is generally comprised of stony and shallow soils (Shackleton and Gambiza, 2008), which makes it susceptible to erosion.

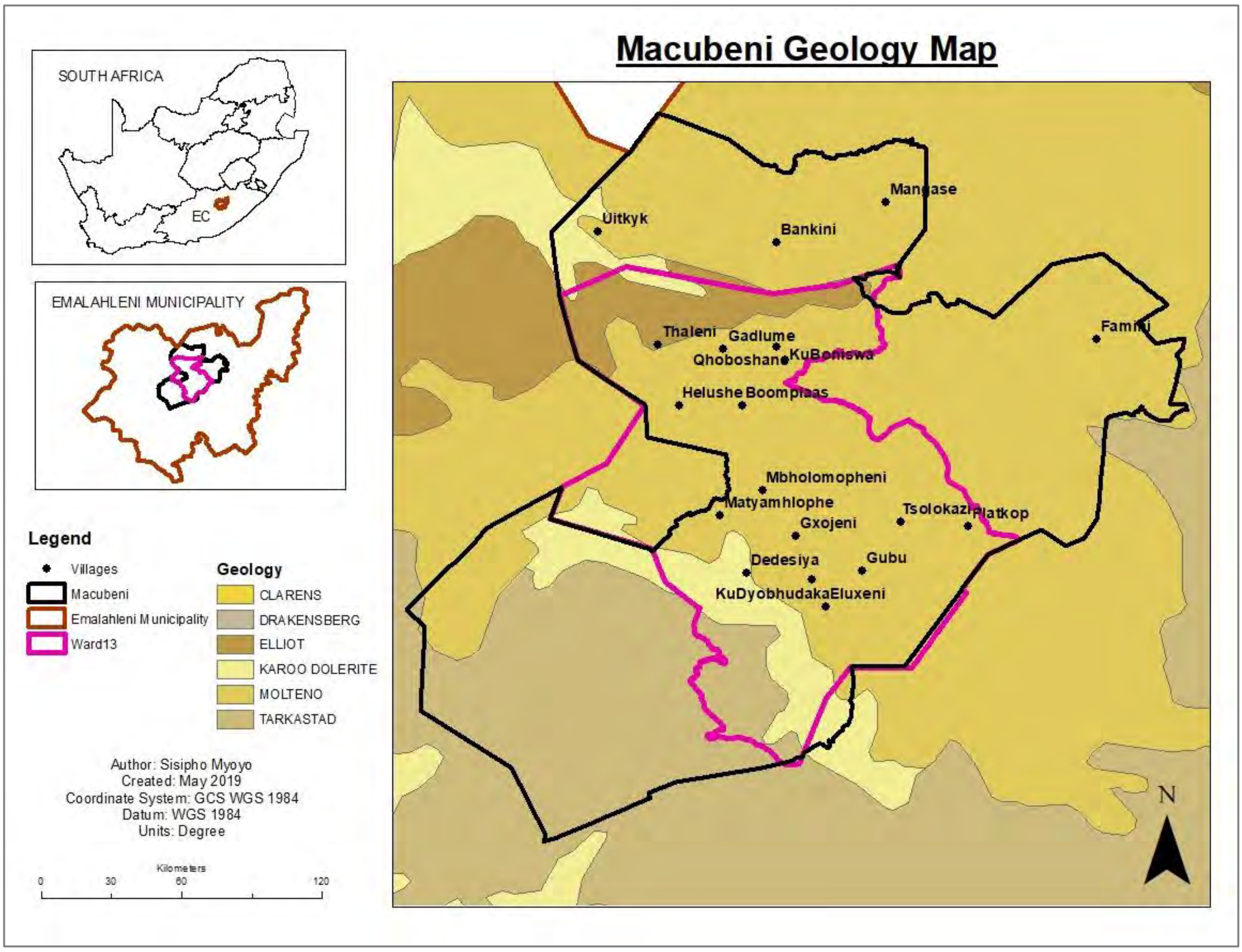


Figure 3.3 : Macubeni geology Map (GEF 5 SLM Project)

Macubeni is considered as one of the most degraded communal lands in the Eastern Cape, and possibly in South Africa as a whole (Fabricius and Cundill, 2010; Hoffman and Todd, 2000). Evidently, gully erosion is a major challenge in the area (Figure 3.4) and the eroded soil gets deposited into the rivers in the catchment (Fabricius and Cundill, 2010).

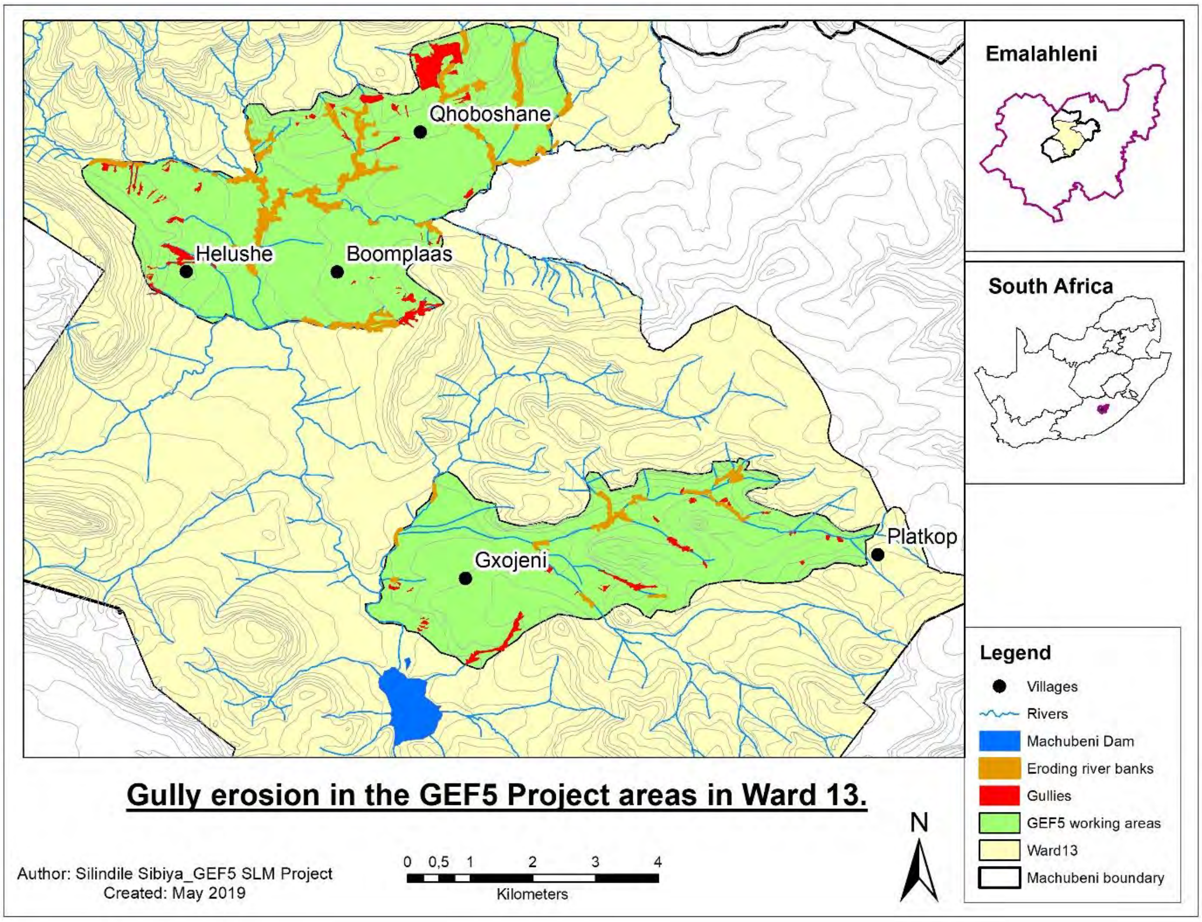


Figure 3.4: Macubeni gully erosion map (GEF 5 SLM Project)

3.4. Land use and Vegetation

Mucina and Rutherford (2006) describe the natural vegetation as a dense grassland of the Tsomo and the Southern Drakensberg Highland Grassland vegetation type (Figure 3.5) which is dominated by species such as *Tristachya leocothrix, Elionurus muticus, Themeda triandra, Eragrostis curvula and Heteropogon contortus* (Bredenkamp et al., 1996). *Euryops floribundus* or Lapesi as commonly referred to by the local community, is an expansive species which has invaded the degraded landscape (Figure 3.6) (Mucina and Rutherford, 2006). In addition, livestock grazing and arable agriculture are the most extensive uses of the land in Macubeni (Shackleton and Gambiza, 2008), which further subjects the land to soil erosion. The invasion of Lapesi in the rangelands impedes grass production. However, the woody species is also useful to the locals as they use it as fuel and stockade fencing (Shackleton and Gambiza, 2008). Although grazing is one of the dominant land uses in Macubeni, the percentage of palatable grass species such as *Themeda triandra* which is indicative of a healthy rangeland, are found to be of low abundance (Molepo et al., 2017).

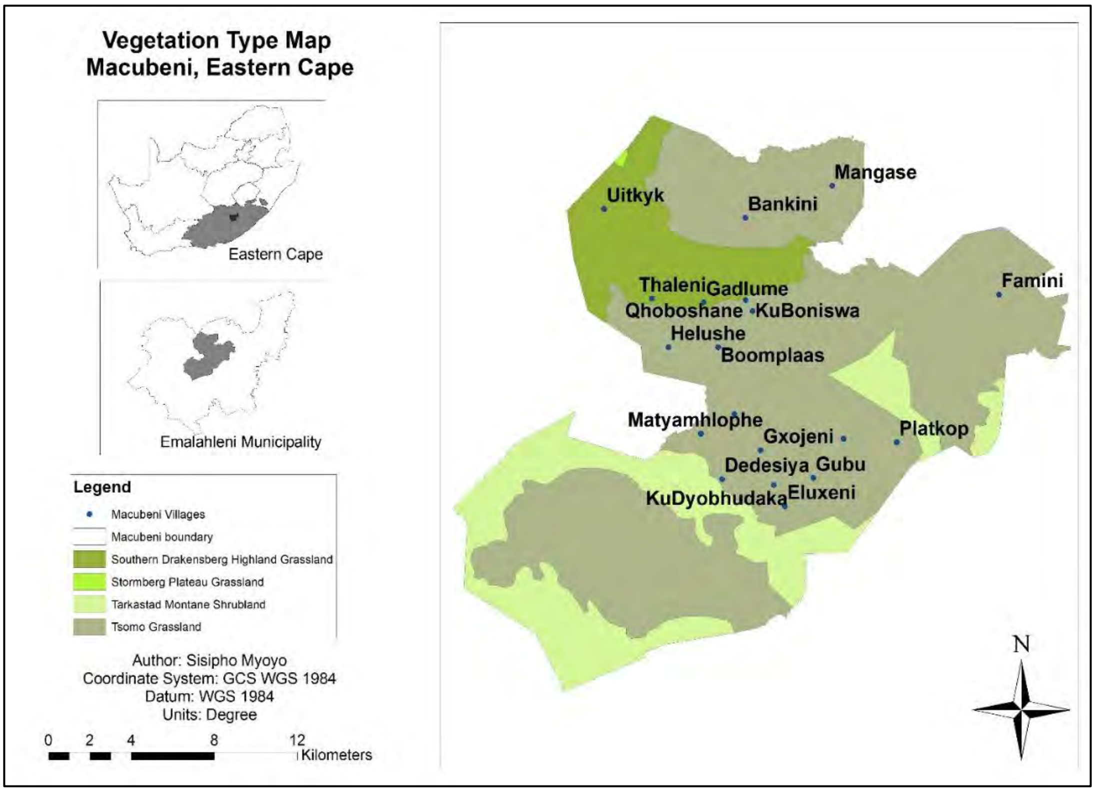


Figure 3.5: Vegetation cover map in Macubeni

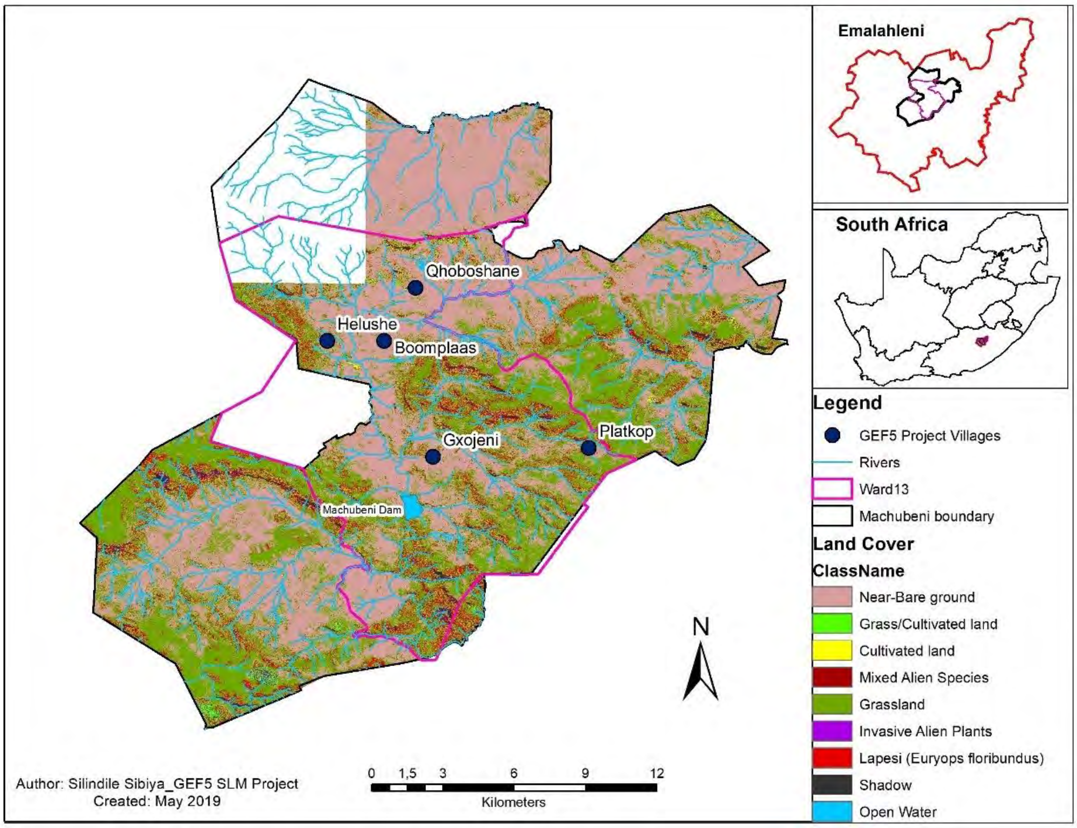


Figure 3.6: Macubeni land cover map

Chapter 4. Research methods

4.1. Introduction

This chapter highlights the details of the methods that were applied to achieve the objectives outlined in the first chapter.

4.2. Research design

The research followed an empirical-analytical approach, using both quantitative and qualitative data through desktop software such as ArcGIS (ESRI) and Vensim © v.8.1.0 2019 (Ventana Systems), and a multi-criteria analysis MCA tool in Microsoft Excel.

Four main interconnected method processes were used in this study (see Figure 4.1). The rectangles in Figure 4.1 represent the main steps in the research process, with the numbered circles showing the overall sequence. The thick coloured arrows between the research steps denotes the primary process flow, with the solid black arrows denoting the main iterations in the form of 'reviews'. Finally, the dashed arrow shows one-way input from the spatial analysis into the leverage points analysis.

The first step in the multi-method approach was a process of mapping the crop fields according to their usage and degradation levels (detailed in section 4.3.1). The next step (Step 2, detailed in section 4.3.2) was undertaking a literature review and conduct stakeholder engagements to understand abandoned fields drivers and their relationship with degradation. Step 3 (detailed in section 4.3.3) was done through systems mapping by using causal loop diagrams. The fourth step was to conduct a Multi-Criteria Analysis (MCA) of the interventions undertaken in the study site in relation to abandoned fields (Step 4, detailed in section 4.3.4), which led to a review of the systems diagrams (Step 5). A leverage points analysis (Step 6) was used to synthesise the first four processes which drew from the results of the spatial analysis, the MCA, and systems mapping (as described in section 4.3.5). The leverage points analysis was used to refine the systems diagrams (Step 7), leading to the final discussion and recommendations arising from this study (Step 8).

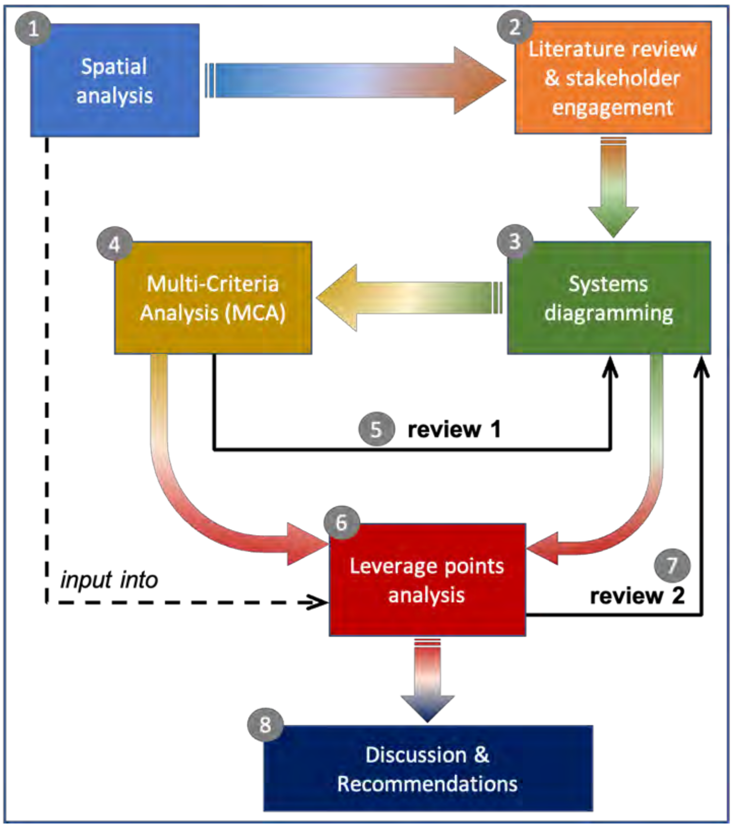


Figure 4.1: Summary of the research process

4.3. Data collection and analysis

4.3.1 Crop fields mapping

The first objective was to map and classify the extent of land degradation on currently cultivated and previously cultivated crop fields in Macubeni. To achieve this objective, I used the methods that were adapted from Schlegel et al. (2018) and Huchzermeyer et al. (2018).

Digital aerial photographs of Ward 13 used here were from 2015 and sourced from National Geo-Spatial Information, Pretoria. Images from 2015 were used because they were the latest available aerial photographs of Ward 13 at the time this study was conducted. Satellite images such as those from Sentinel and Landsat that were more recent could not be used because a higher pixel quality was required to map the crop fields as accurately as possible. Therefore, the photographs used were captured at a scale of 1:10 000 with 0.5 m resolution, which are clear enough to identify even the small crop fields (<10 ha). The crop fields of Ward 13 were identified from the digital aerial photographs and mapped using the GIS digitising tool on ArcMap v.10.6.

Since this study was conducted on a ward level and wards are institutional boundaries, I acknowledge that cultivated fields do not conform to such boundaries. Therefore, a clipping tool was utilised on

ArcMap to overlay municipal and biophysical boundaries. Unlike the cultivated fields, some abandoned fields have a faint margin, therefore the accuracy of digitising them can be somewhat limited. Furthermore, smaller fields (< 10 ha) close to each other in the villages and falling under the same status and degradation level, were merged into one polygon.

The crop fields were assigned codes 1, 2 or 3 through an attribute table created in ArcMap and classified according to status, degradation and encroachment. Microsoft Excel was used to calculate values such as the total percentage of different classes in terms of the area they each cover, and to display the results on graphs.

4.3.1.1 Crop field classification

A. Status

Status refers to the usage of the crop field (displayed in Figure 4.2 and Figure 4.3) where:

1 = used (currently/ recently ploughed)

2 = partly used (a portion of a crop field still ploughed)

3 = Abandoned (old/ unused)

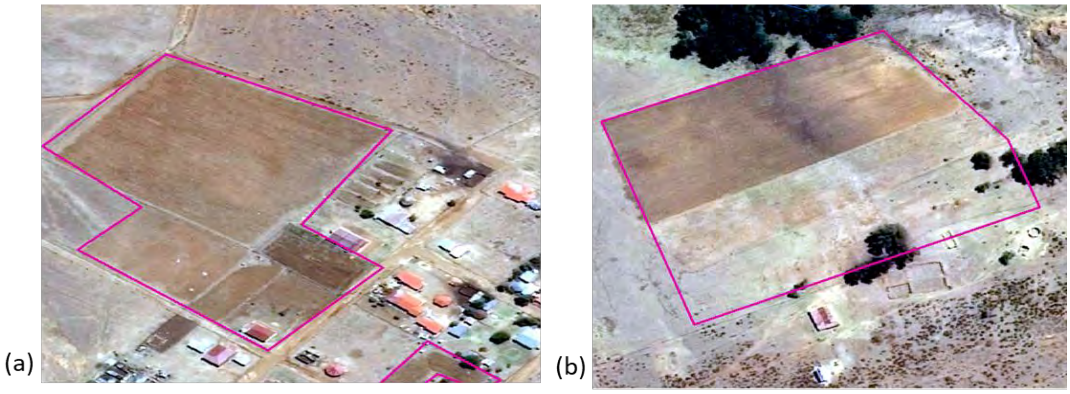


Figure 4.2: (a) Example of a clearly used crop field (status 1). (b) Example of a partly used crop field (status 2)

Figure 4.3: Example of an abandoned crop field (status 3)

B. Degradation

This indicates the current condition of a crop field with respect to visible erosional features such as rills, gullies and lack of vegetation cover as indicated in Table 4.1. Moreover, each degradation class is subdivided into three vulnerability codes. These refer to the probability of future degradation of the land through erosion or bush encroachment in the absence of any mitigation measures.

Table 4.1: Degradation and vulnerability codes for crop fields. Adapted from (Schlegel et al., 2018).

Degradation Code	**Description**		**Vulnerability Code**	**Description**
1	Low degradation: *No rills/gullies*		**1**	Unlikely to degrade (low)
			2	Erosion encroaching on cultivated land (moderate)
			3	n/a (not applicable)
2	Moderate degradation: *Rills, small gullies, lack of vegetation and/or sheet erosion*		**1**	Low erosion risk (erosion stable, low)
			2	Moderate erosion risk (moderate)
			3	High erosion risk (formation of larger gullies visible, high)
3	High degradation: *Abundant erosion*		**1**	n/a (not applicable)
			2	Moderate erosion risk (moderate)
			3	High erosion risk (high)

Figure 4.4 and Figure 4.5 illustrates examples of how different degradation levels look on crop fields from an aerial photo used for mapping.

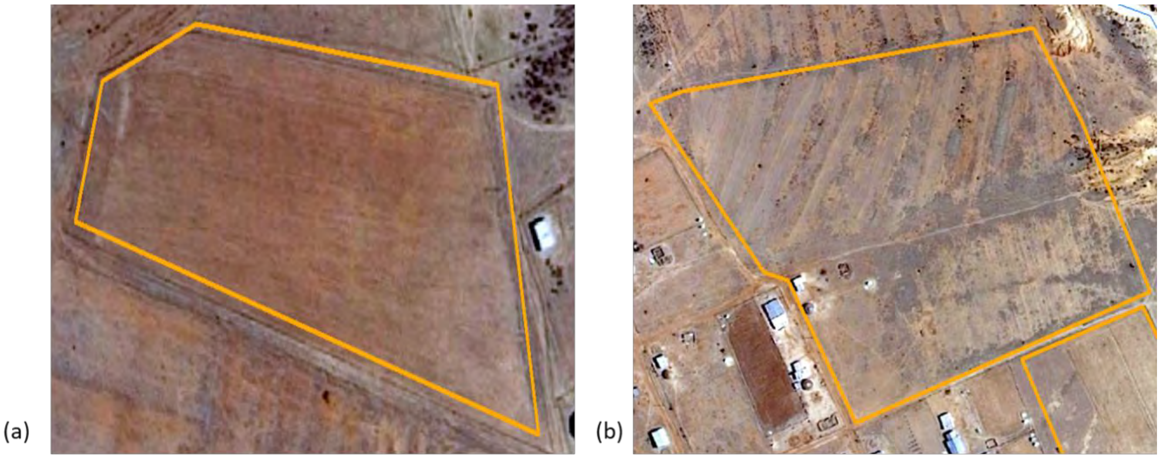


Figure 4.4: (a) Example of a crop field with little to no degradation (code 1). (b) Example of a crop field with moderate degradation (code 2)

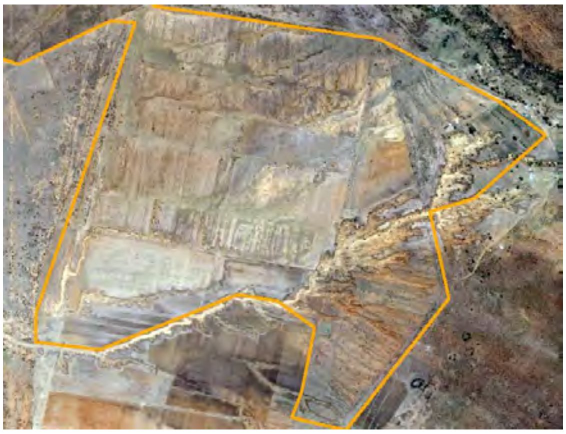


Figure 4.5: Example of a highly degraded and highly vulnerable crop field (code 3)

C. *Encroachment by woody species*

The encroachment in this case is by woody expansive species such as *Euryops floribundus* (Lapesi) shrubs (Figure 4.6). These plants are indicative of degradation as they tend to thrive on degraded environments and supress the effective growth of grass species around them (Gxasheka et al., 2019). The density of the encroachment in each crop field was scored according to the descriptions in Table 4.2.

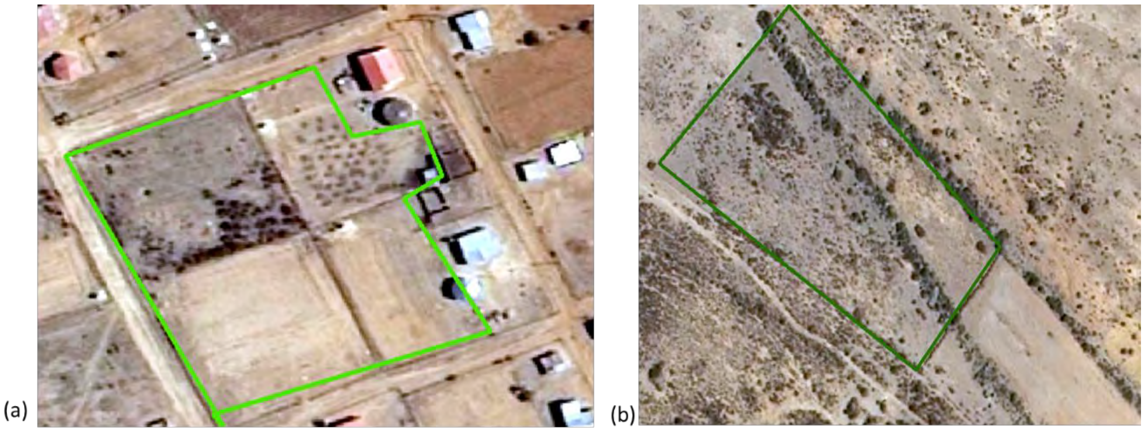


Figure 4.6: (a) An example of a moderately and (b) heavily encroached crop field

Table 4.2. Crop fields encroachment scores

Encroachment code	Description
1	Little or no encroachment (0-10 %)
2	Moderate encroachment (11-50 %)
3	Heavy encroachment (> 50 %)

4.3.1.2 Statistical tests of correlation

A nonparametric statistical technique called the Chi-Square Test of Independence was used to determine if the different degradation levels have a significant relationship with the usage status of the fields. The hypotheses stated were:

- Null hypothesis (H_0): There is no significant relation between usage status and degradation level in crop fields.
- Alternative hypothesis (H_1): There is a significant relation between usage status and degradation level in crop fields.

The formula in Equation 1 was used:

$$X^2 = \sum \frac{(Oi-Ei)^2}{Ei} \qquad (1)$$

Where:

X^2 = Chi-square

Oi = observed value

Ei =expected value

The expected value was calculated by multiplying the row total with the column total and dividing that by the total count of all the fields. A standard significance level of 0.05 was used with a degree of freedom value that is calculated using the formula [number of rows-1 x number of columns -1] in Microsoft Excel to find the critical value (CV). The critical value defines the cut-off point in the test distribution area where the null hypothesis is accepted or rejected. It was calculated through the use of the “CHISQ.INV.RT” function in Excel.

The “CHISQ.TEST” function was further used to calculate the p-value, which determines whether to reject or fail to reject the null hypothesis based on the significance level. If $p \leq 0.05$ then the null hypothesis is rejected and the alternative hypothesis is accepted. If $p \geq 0.05$ then the null hypothesis is not rejected.

Furthermore, to deduce the relative strength of the correlation between the tested variables, the Cramer’s V Test was calculated and further interpreted using the values listed in Figure 4.7, as per the formula in Equation 2:

$$V = \sqrt{\frac{X^2}{N*min(r-1),(c-1)}} \tag{2}$$

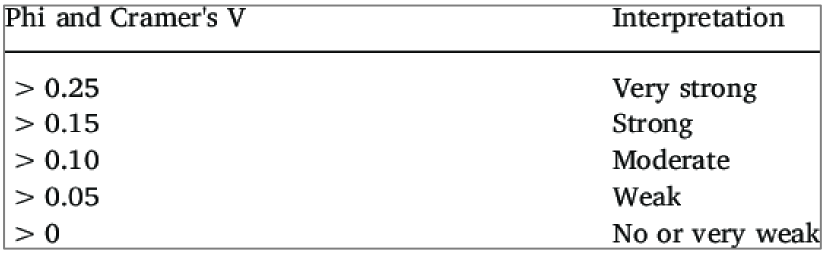
where:

X^2 = Chi-square

$n =$ total number of sample

$r =$ number of rows

$c =$ number of columns



Phi and Cramer's V	Interpretation
> 0.25	Very strong
> 0.15	Strong
> 0.10	Moderate
> 0.05	Weak
> 0	No or very weak

Figure 4.7: Interpretation of Cramer’s V Test (Akoglu, 2018; p92)

4.3.1.3 Normalised vegetation index

The Normalised Difference Vegetation Index (NDVI) was used on the mapped fields to compare the vegetation growth vigour on the fields. The images (image: LC08_L2SP_170082_20200101_20200823_02_T1_SR_B1 to band 7) used for the NDVI calculation [formula: NDVI = (NIR - R)/ (NIR + R)] are of Landsat 8 band 1 to band 7 downloaded from an open-source website named USGS (United States Geological Survey) Earth Explorer. The images were compiled into a composite image through an image analysis tool in ArcGIS to do the NDVI analysis. The image pixel size was 30m by 30m. This image analysis enables one to identify areas that are possibly degraded or abandoned using vegetation cover conditions. The NDVI values range between -1 and +1, where values closer to -1 indicate poor to no vegetation, while those which are closer to 1 are indicative of high photosynthetic activity, thus good vegetation cover (Dalu et al., 2013).

4.3.2 Case studies for abandoned fields drivers

The potential drivers of degradation and field abandonment were drawn from studies undertaken in Macubeni and literature with case studies of similar catchment characteristics as those of Macubeni. These characteristics include a common nationality (i.e., all case studies are South African) and a common factor of being rural landscapes. Other similarities that were considered for case study comparison were biophysical similarity (including elevation, vegetation, and soil types) and socio-economic similarity (including the socio-economic history of the case studies, the combination of existing land tenure arrangements, and the land uses). The tenure arrangements in this case refer to the historical apartheid South African government laws which based land tenure rights on racial segregation (Kirsten et al., 1994; Ngidi, 2014). Land uses include crop agriculture and livestock farming, which increased pressure on land (Shackleton and Gambiza, 2008).

4.3.3 Systems mapping

The second objective of this study was to develop a qualitative systems model through causal loop diagrams describing the interaction between crop fields degradation and SLM interventions. A specialised system dynamics (SD) modelling software, Vensim © v.8.1.0 2019, was used to achieve this objective.

4.3.3.1 The use of systems diagrams

There are multiple reasons why systems diagrams are used. These include communicating how complex and systematic a problem is, being able to codevelop shared views, and to conceptualise a problem (Maani and Cavana, 2007) . These multiple reasons integrate to address the main goal of intercepting "wicked problems" (difficult problems). Systems diagrams can also be used to clarify competing views and find common ground (Maani and Cavana, 2007). To achieve these objectives, diverse variables are connected to each other to create systems pictures/maps which are best developed iteratively to suite the problem at hand. The iterative aspect of systems diagramming also enables the identification of high leverage points, where the implementation of various potential solutions would be most impactful within a complex system (Maani and Cavana, 2007). Moreover, through systems diagrams, mental models and their underpinning assumptions can be revealed and further support finding common ground between opposing views. The transparency of mental models in a systems diagram enables one to see both the finer details and the broader perspective of a problem (i.e.," seeing the forest and the trees"), as opposed to focusing on only one part, and shows how different components interact with each other as a system (Meadows, 1999).

Figure 4.8 summarises the process of a system dynamics modelling process, where six (I-VI) main steps with multiple iterations in between each step are followed. Ordinarily, a modelling process ends with producing a simulation model which is tested and can be used for analysing different scenarios and policies. This study only focused on the first two steps of the modelling process as indicated in Figure 4.8 (highlighted in yellow). This is because Macubeni is a data poor catchment and there were not enough components of the system that could be represented quantitatively. Consequently, this study did not apply the entire modelling process to the stage of quantitative analysis through a computer simulation.

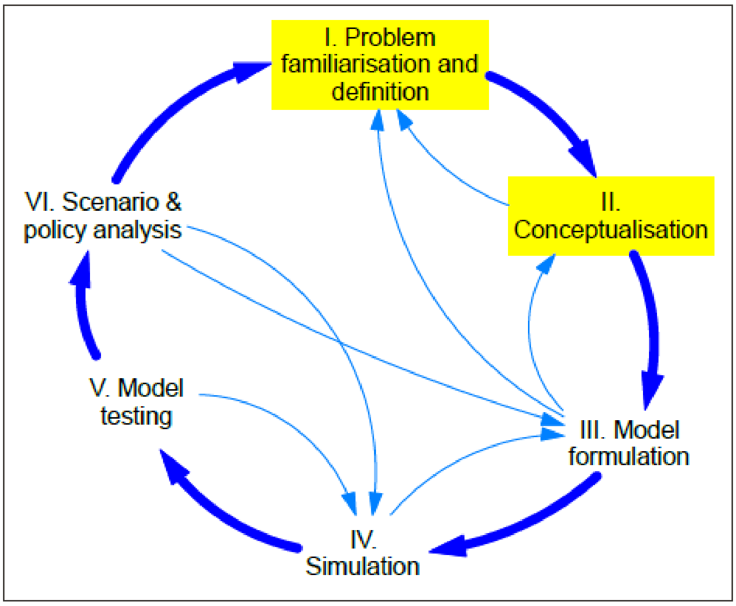


Figure 4.8: A typical system dynamics modelling process, showing the primary modelling sequence in bold blue arrows and the feedbacks between steps in thinner, light blue arrows. Adapted from (Vermeulen et al., n.d.).

4.3.3.2 What are causal loop diagrams?

Drawing from the system dynamics approach, this study applied a specific type of systems mapping called causal loop diagrams (CLDs). CLDs are a tool used for delineating the causal relationships of various elements in a complex and non-linear fashion (Sterman, 2001). This tool is often used as a foundation during the conceptual stages of system dynamics modelling to develop hypotheses of how the different elements influence each other. CLDs can be used for both solely analytical purposes and stakeholder engaged research (Pollard et al., 2008). As done so in this study, Maani and Cavana (2007) expressed that through the application of CLDs, several important questions can be addressed, such as:

- What are the key variables in the situation of interest?
- How do these variables link to one another?
- How do these variables affect each other?
- Does a variable have a reinforcing or balancing effect on the variables it is linked to?
- Where are possible intervention points (i.e., levers for change)?

4.3.3.3 The mechanism of CLDs

Interactions between several variables can be modelled with both their positive and negative feedback structures and the direction of future trends influenced by various drivers in the system

(Vafa-arani et al., 2014). The feedback structures are represented by CLDs as shown in Figure 4.9, which illustrate the cause-and-effect relationship between parameters in the system aspect (Sterman, 2001). The arrows display either a positive or negative sign on them to illustrate an effect of one variable to another as being towards in the same direction (+) or opposite direction (-). The positive sign in the middle of one loop indicates that it is a reinforcing loop and consists of either only positive signs (+) or an even number of negative (-) links. The negative loop is indicative of a balancing feedback loop, which has an odd number of positive links.

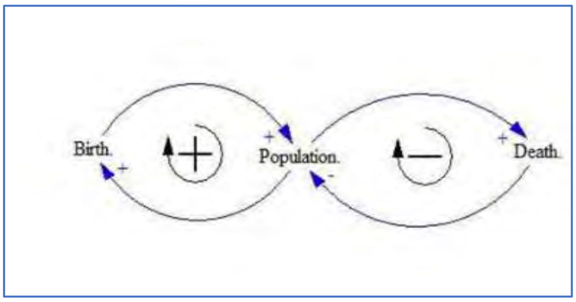


Figure 4.9: Causal loop diagram showing both positive and negative feedback loops (Sukhwal, 2015: 12)

4.3.4 Multi criteria analysis (MCA)

In this study, MCA was integrated with the spatial analysis and the systems diagramming methods. The MCA was used to compare the different sustainable land management interventions identified at through the qualitative systems model. This is a valuable addition to the methods used because it enabled the simultaneous comparison of interventions with considerations of environmental, social, economic, and technological aspects. The MCA was also used to structure the stakeholders' input using qualitative variables such as stakeholders' perceptions of efficacy, and quantitative variables such as the financial costs of the different interventions. The input was solicited during a stakeholder workshop that was run virtually in December 2021 with seven of the GEF5 SLM project team leaders, including representatives of each of the three main project hubs introduced earlier. These stakeholders were appropriate for the workshop based on the fact that they have been working in the subject catchment and with the community members for several years holding workshops with the locals and traditional authorities, conducting trainings and helping people apply various strategic methods of sustainable land management, agriculture and governance. As a result, they have on the ground experience with the socio-economic dynamics in the area. The rating of the different interventions is based on that experience and the feedback they received from the community members in different meetings and workshops held with them over the course of 5years.

Drawing from the approaches outlined by CLG (2009) and Mellville-Shreeve *et al.* (2016) the following steps were employed in the MCA: (1) the problem definition and the decision context were defined by drawing on the initial results of the analyses from the preceding steps (see Figure 4.1); (2) the options to be compared against one another were then defined as the interventions in the case study site; (3) the objectives and criteria that “reflect the value associated with the consequences of each option” were subsequently defined (CLG, 2009: 31); (4) the performance matrix was populated with the MCA results, which were calculated from a combination of cost data and stakeholder input and then converted into consistent numerical values (i.e. normalised); and finally, (5) the performance of the interventions were then evaluated against the criteria.

Table 4.3 shows a generic performance matrix, as used in the MCA step (4). In this generic example, three interventions (A,B,C) are assessed against two criteria (1,2). The criteria are weighted according to perceived relative importance. In this example, Criteria 1 is weighted 30% and Criteria 2 as 70%. The direction of each criteria corresponds with whether higher values of a criterion is desirable (+1) or undesirable (-1). In the case of costs, for example, the lower the cost the better, and so a higher cost undesirable (hence the direction is -1). Each intervention is then scored, with the performance then multiplied against the weighting and the direction (e.g., for Criteria 1, Intervention A’s score was 2, with the weighted performance calculated as 2*0.3*-1, for the result of -0.6).

Further details of the MCA method are explained on a step-by-step basis in Appendix A.

Table 4.3**:** Generic performance matrix. Wt = weight; Wt’d perf. = weighted performance.Multi criteria analysis (MCA)

			Interventions					
			Intervention A		**Intervention B**		**Intervention C**	
	Wt	**Direct-ion**	**Perf.**	**Wt’d perf.**	**Perf.**	**Wt’d perf.**	**Perf.**	**Wt’d perf.**
Criteria 1	0.3	-1	2	-0.6	1	-0.3	4	-1.2
Criteria 2	0.7	1	3	2.1	2.5	1.75	3.5	2.45
Score	-	-	-	1.5		1.45		1.25

4.3.5 Leverage points analysis

As a final step of the multi-method process, the results of the spatial analysis, the MCA, and the systems mapping were synthesised using a leverage points analysis (as shown in Step 6 in Figure 4.1).The leverage points analysis was used to review the systemic conceptualization in order to further refine the systems diagrams by capturing additional variables and feedback loops that were surfaced through the preceding steps (this refinement is labelled as ‘review 2’, Step 7, in Figure 4.1). The Leverage Points framework, summarized in Figure 6.1 in chapter 6, was used to structure the analysis of the interventions, the implications of which form the basis of the final discussion and the recommendations emanating from this study (Step 8).

Chapter 5. Crop fields mapping and analysis

5.1. Overview of Macubeni crop fields

To determine the extent of land degradation on cultivated fields and investigate whether they are being used or have been abandoned, a total of 840 crop fields were mapped out, which covered an area of 3159.95 ha in total. The crop fields equate to 20.81% of the total area of ward 13 of the Macubeni catchment. It must however be noted as mentioned earlier in the methods chapter, that not all the crop fields were mapped out individually. Most of the small fields (<10 ha) were found around the village homes (Figure 5.1) and have the same usage and degradation status, therefore a few were grouped together into one polygon to make it into a slightly bigger one. In doing so, the total area of the crop fields remained undistorted, which in this case was found to be a total of 3159.95 ha. The bigger crop fields (>10 ha) are mostly located away from the village houses and close to riverbanks.

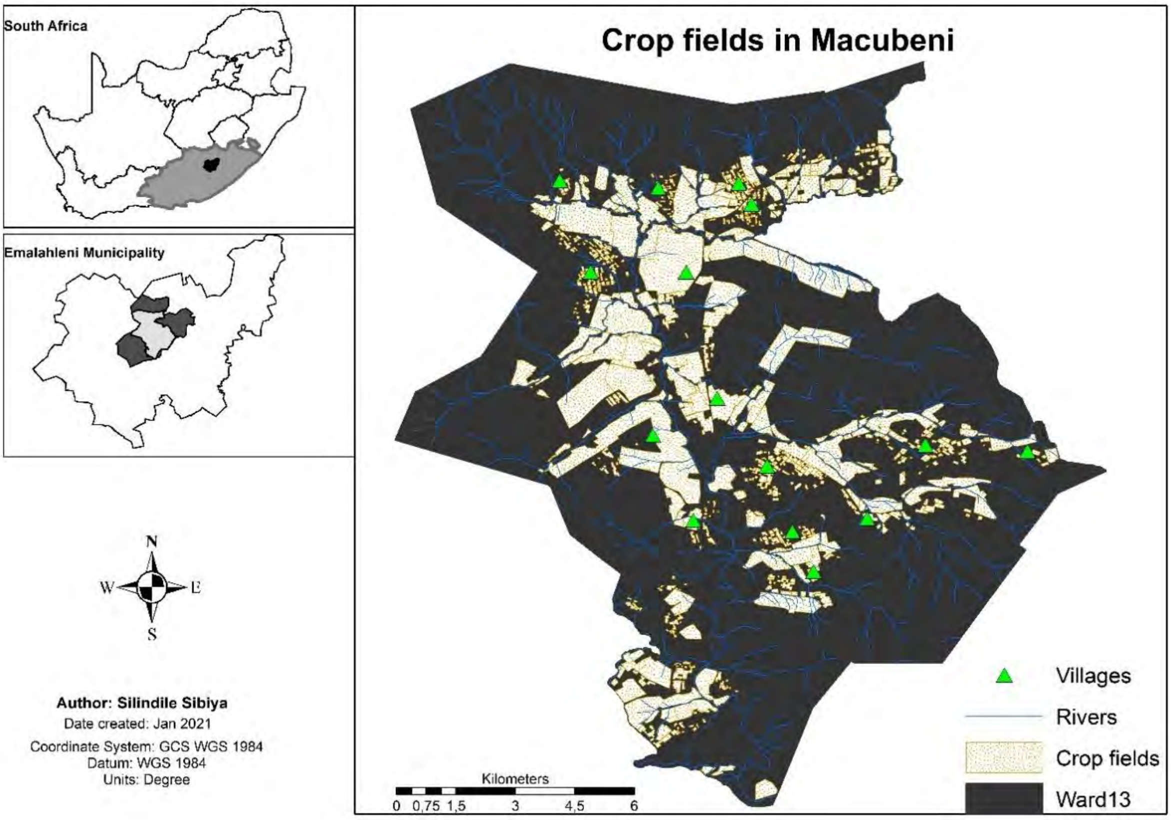


Figure 5.1: Crop fields locality in Macubeni.

5.2. Status of crop fields

All the mapped cultivated fields in the study area were classified according to the usage status (Table 5.1), as the first step in determining the state that each crop field was in. Almost half of the number of mapped fields (47%) were partly used, followed by abandoned fields at 30% and the lowest was used fields, which were a total of 23%. The same trend was seen on the percentage area covered by the fields from each of these classes (Figure 5.2), which is a more important factor than the count of the fields. The biggest area coverage of 1666.07 ha (52.72%) was attributed to partly used fields and the lowest was the used fields with only 10% out of all the crop fields in the area. The percentage area covered by each class in reference to the entire ward was of course smaller (Table 5.1), as this included the entire surface land within the ward boundary such as mountains, settlement areas and rangelands, which are not areas for cultivation.

Table 5.1: Status of crop fields in Macubeni

Status	**Total no. of fields**	**Total area (ha)**	**Area out of all fields (%)**	**Total area in the Ward (%)**
Used	197	309.97	10.00%	2.04%
Partly used	394	1666.07	52.72%	10.97%
Abandoned	249	1183.92	37.47%	7.80%
Total	**840**	**3159.96**	**100%**	**20.81%**

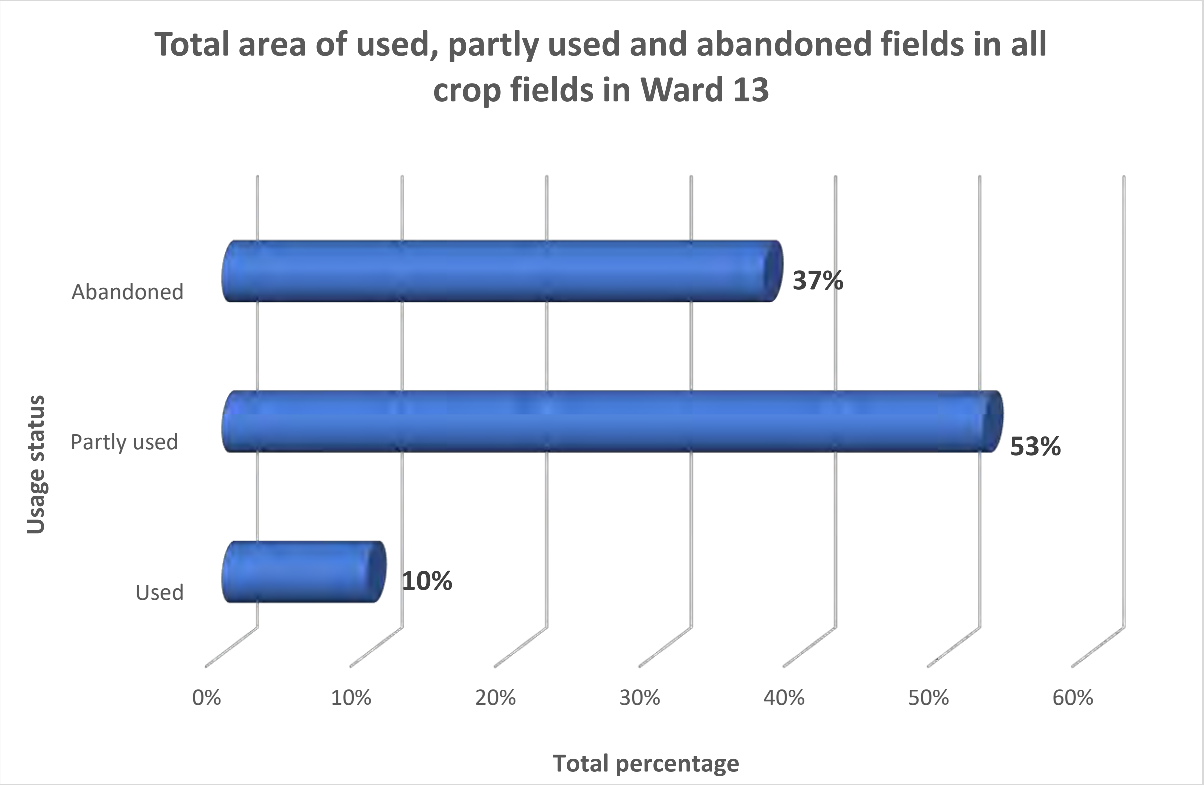


Figure 5.2: The percentage of area covered by the different status categories in Macubeni

The bigger fields as displayed on the map in Figure 5.3 are mostly located on the outskirts of the area, compared to the smaller fields which are in the settlement area. These bigger fields are also located right next to rivers.

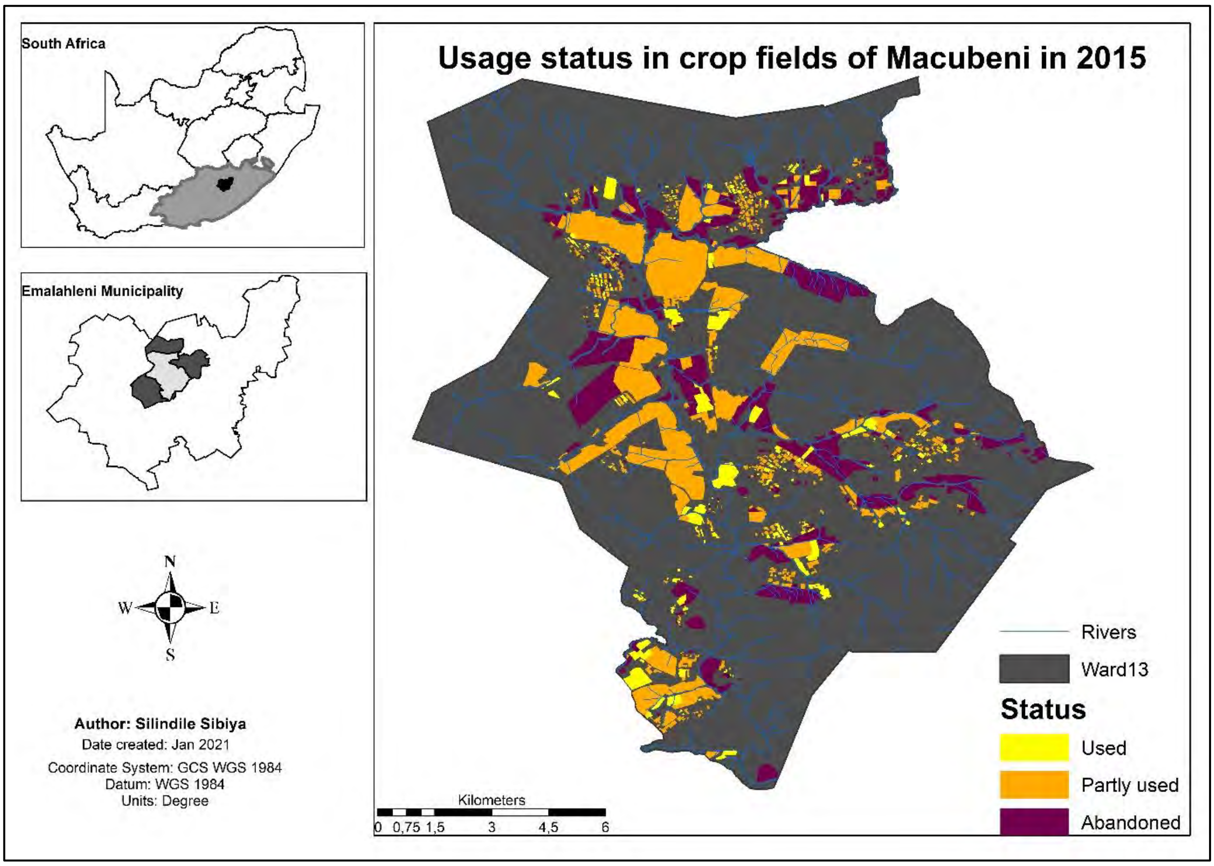


Figure 5.3: A map showing the spatial distribution of used, partly used and abandoned crop fields in Macubeni.

5.3. Degradation level in the crop fields

As described in the methods chapter, the levels of degradation in this study were defined using three codes. Code 1 classified low degradation (no rills/gullies and low vulnerabilty to future erosion), code 2 classified moderate degradation (presence of rills, small gullies, lack of vegetation and/or sheet erosion), and code 3 classified high degradation (abundant erosion and big gullies).

An area of 1498.19 ha (out of the total 3159.96 ha) which is the largest portion (47.41%) of the total mapped crop fields area was found to be highly degraded, despite the number of fields in this class being the smallest (Table 5.2). This is due to the fact that the highly degraded fields are mostly the big crop fields (Figure 5.4), which cover a large area. Moderately degraded fields covered the second largest area of 1138.03 ha (36.01% of all the crop fields), while those that displayed signs of low degradation covered the smallest area of 523.73ha (16.57% of all the crop fields). The maximum area coverage out of the whole ward was 9.87% from the highly degraded, 7.49% from moderately degraded, and 3.45% from the fields with little to no degradation.

Table 5.2: A summary of the degradation levels of crop fields in Macubeni

Degradation status	Total no. of fields	Total area (ha)	Area out of all fields (%)	Total area in the Ward (%)
Low	464	523.73	16.57%	3.45%
Moderate	301	1138.03	36.01%	7.49%
High	75	1498.19	47.41%	9.87%
Total	**840**	**3159.95**	**100%**	**20.81%**

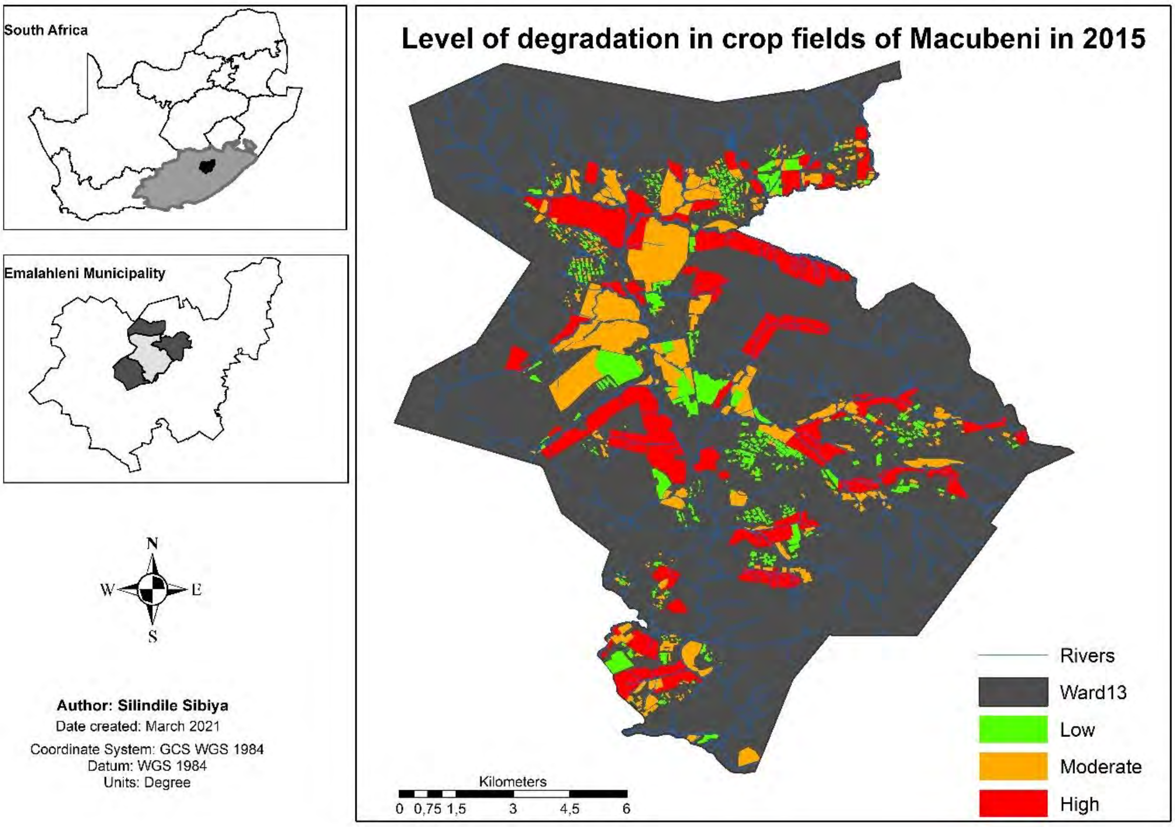


Figure 5.4: The levels of degradation identified in crop fields

Most of the highly degraded fields were those that were partly used and those which had been abandoned, with a total of 26.01% and 20.02% respectively. A much lower area of only 1.38% from used fields was highly degraded.

5.4. Vulnerability level in the crop fields

The vulnerability level of crop fields speaks to the potential risk that the area will be degraded in the future, judging by the features already exhibited by the crop field itself or the characteristics of the surrounding area. Table 5.3 shows that the moderately vulnerable fields are the largest in quantity, with 577 fields in total. However, these do not make up most of the total area.

Table 5.3: Vulnerability levels of crop fields in Macubeni

Vulnerability status	Total no. of fields	Total area (ha)	Area out of all fields (%)	Total area in the Ward (%)
Low	39	27.93	0.88%	0.18%
Moderate	577	1093.36	34.60%	7.20%
High	224	2038.66	64.52%	13.43%
Total	**840**	**3159.95**	**100%**	**20.81%**

The highly vulnerable fields amount to a total area of 2038.66 ha, which means 64.52% of all the mapped fields fall into this category, while the moderately vulnerable makes 34.60% and the low vulnerability with only 0.88%% (27.93 ha) of the total mapped fields area. In relation to the entire catchment as displayed geographically on the map in Figure 5.5, the high vulnerability crop fields make up 13.43% of the area.

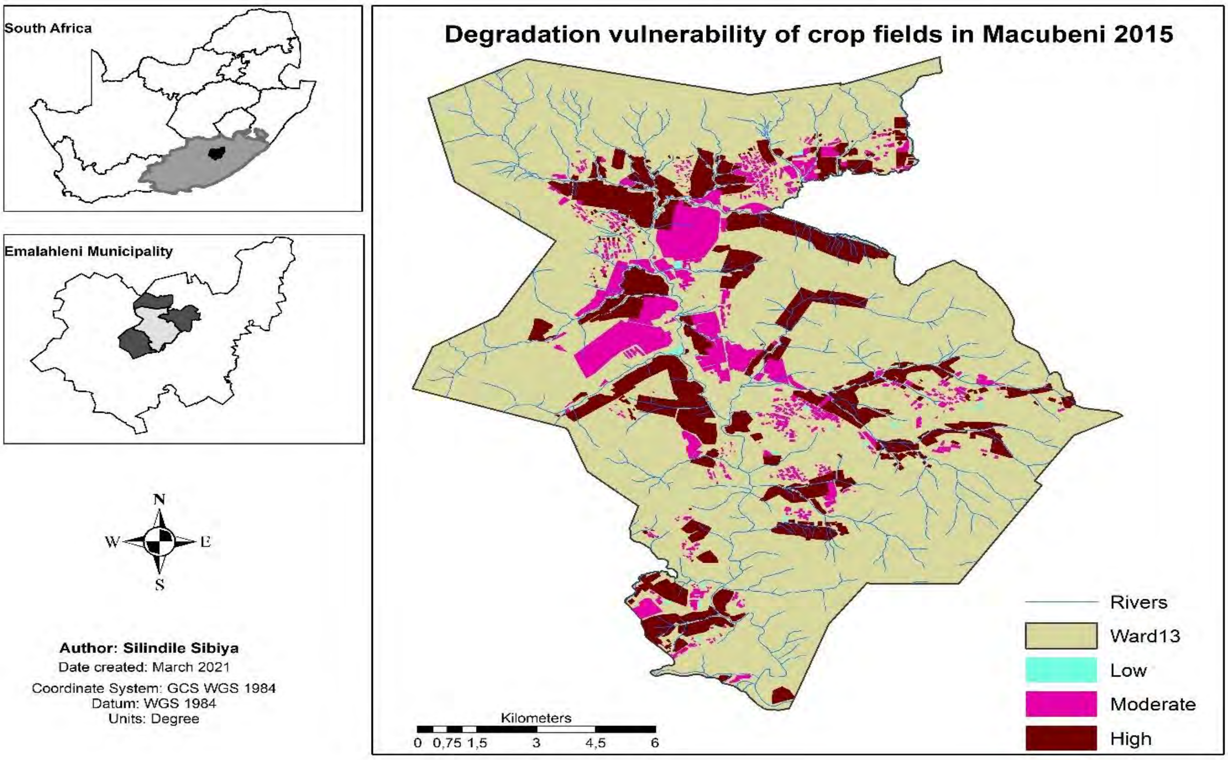


Figure 5.5: A map showing the vulnerability to degradation in crop fields at Macubeni

5.5. Enchroachment level in the crop fields

The results revealed that levels of encroachment on the cultivated lands of Macubeni through invasive species was substantially of the same status throughout the catchment. These species were not specifically identified and classified in the field as this was a desktop study. Out of 840 crop fields identified in the catchment, 825 of them (96% of all the crop fields) exhibited little to no encroachment (Table 5.4). These make up a total area of 3024.57ha and 19.92% of the catchment area.

Table 5.4: A summary of enchroachment levels on crop fields in Macubeni

Encroachment status	Total no. of fields	Total area (ha)	Area out of all fields (%)	Total area in the Ward (%)
Low	825	3024.57	95.71%	19.92%
Moderate	6	3.09	0.10%	0.02%
High	9	132.29	4.19%	0.87%
Total	**840**	**3159.95**	**100%**	**20.81%**

The map in Figure 5.6shows that the highly encroached fields are those that have been abandoned and on the outskirts of the catchment away from settlement areas. The highly encroached fields make up only 132.29 ha (4.19% of the identified fields) which is 0.87% of the greater catchment area.

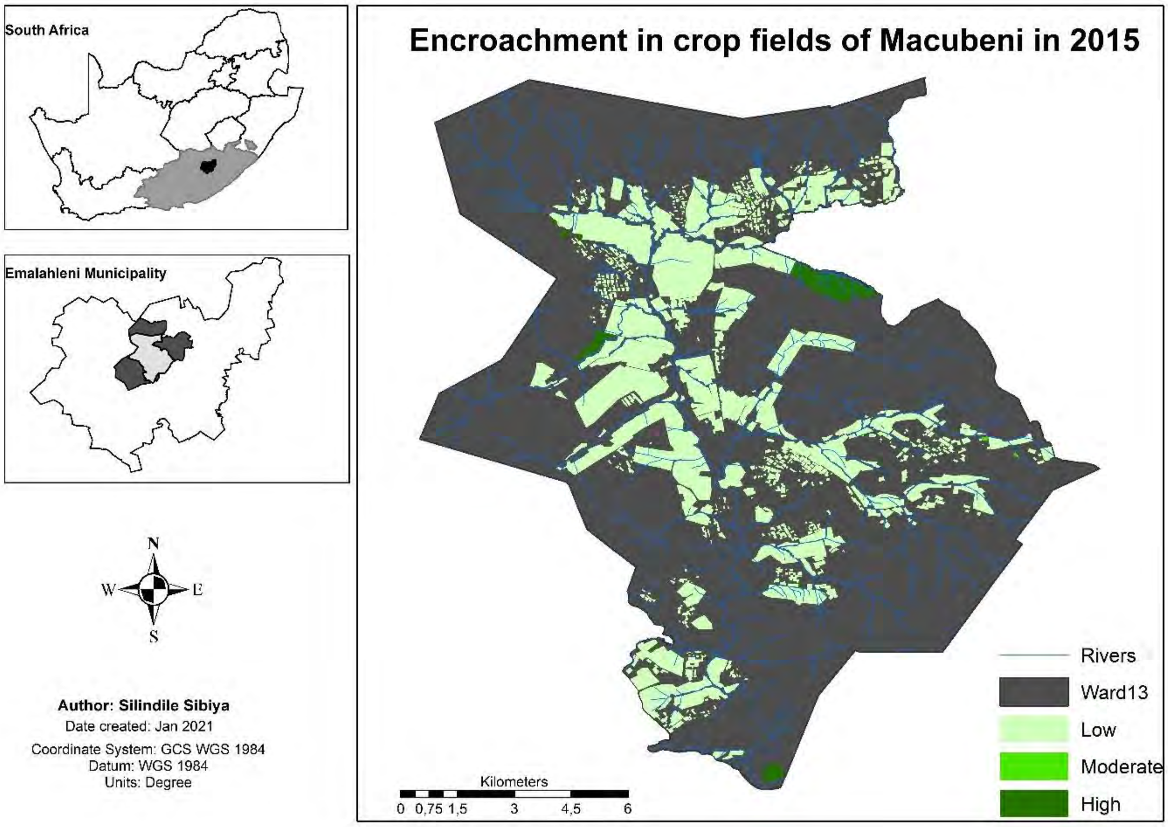


Figure 5.6: The encroachment levels in crop fields of Macubeni

5.6. Condition of crop fields in Macubeni

The previous sections (5.2 – 5.5) summarised the usage status, degradation level, vulnerability, and encroachment categories independently. This section documents the details on all the different categories in relation to one another, i.e. how degraded and vulnerable to future erosion are the used fields, partly used fields, and abandoned fields in the catchment (Table 5.5-Table 5.10).

5.6.1 Degradation in used fields

Table 5.5 shows that out of the 309.97 ha of total land area identified as used crop fields, half (153.84 ha) of it is made up of fields with low degradation. Interestingly, even though used fields are usually the ones with the most exposed soil, there is only a small portion of 43.69 ha (14% of used fields) of used fields that exhibited high degradation (score of 3). These are fields that have clearly visible large gullies and no vegetation cover.

Table 5.5: Degradation levels in used crop fields

Degradation (Used)	No. of crop fields	Area (ha)	Percentage (%) area covered (all crop fields)	Percentage (%) of Ward
Low	143	153.84	4.87%	1.01%
Moderate	51	112.44	3.56%	0.74%
High	3	43.69	1.38%	0.29%
Total	**197**	**309.97**	**9.81%**	**2.04%**

Vulnerability codes were used to estimate the potential of crop fields to exhibit further erosion at different degradation levels (Table 5.6). Most (98%) of the used fields with low degradation have moderate vulnerability to future erosion.

Furthermore, Table 5.6 shows that used fields which display moderate degradation are mostly highly vulnerable, with 39 fields out of 50 (78%) being classified as such. Most importantly, the total area of fields in the moderately degraded category with high vulnerability is also the largest with 101.32 ha. These fields either have small gullies running through them, which have a high potential of further incising or there are bigger gullies in the immediate surrounding area.

Lastly, the entire 43.69 ha of all used fields area that displayed high degradation also present high vulnerability.

Table 5.6: Vulnerability of used crop fields within different degradation levels

Degradation	Vulnerability	No. of crop fields	Area (ha)	Percentage (%) area covered (all crop fields)	Percentage (%) of Ward
Low	Low	3	2.22	0.07%	0.01%
	Moderate	140	151.61	4.80%	1.00%
Moderate	Low	2	0.38	0.01%	0.003%
	Moderate	10	10.74	0.34%	0.07%
	High	39	101.32	3.21%	0.67%
High	Moderate	0	0.00	0.00%	0.00%
	High	3	43.69	1.38%	0.29%
Total		**197**	**309.97**	**9.81%**	**2.04%**

5.6.2 Degradation in partly used fields

Partly used fields were found to be the category that holds the largest total area of 1666.07 ha (52.72%) amongst all the identified crop fields (3159.96 ha). This category is further analysed in Table 5.7, which shows that the fields showing low degradation were the smallest group (331.24 ha). This is followed by the moderately degraded fields, which make a total area of 512.86 ha from the total 1 666.07 ha of partly used fields. Lastly, the results in Table 5.7, also indicate that the majority of partly used fields (821.97 ha of 1 666.07 ha) are highly degraded.

Table 5.7: Degradation levels in partly used crop fields

Degradation (Partly used)	No. of crop fields	Area (ha)	Percentage (%) area covered (all crop fields)	Percentage (%) of Ward
Low	272	331.24	10.48%	2.18%
Moderate	107	512.86	16.23%	3.38%
High	15	821.97	26.01%	5.41%
Total	**394**	**1666.07**	**52.72%**	**10.97%**

Table 5.8 indicates that the fields showing low degradation are the smallest group but are almost all moderately vulnerable to future erosion (328.85 ha out of 331.24 ha). A majority of the moderately degraded fields are moderately vulnerable (274 ha out of 512.85 ha), which is 8.67% of all the mapped crop fields. The second biggest area in the moderately degraded category was classified as highly vulnerable fields, which covered 226.68 ha.

Additionally, as anticipated, none of the highly degraded fields exhibited low or moderate vulnerability (Table 5.8). Since they are already currently highly degraded, they were automatically put at a high risk for further degradation. Therefore, all 821.97 ha of highly degraded fields were highly vulnerable. The future degradation risk is of course dependent on whether any rehabilitation measures are taken to minimise further degradation (i.e. stabilising gullies).

Table 5.8: Vulnerability of partly used crop fields at different degradation levels

Degradation	Vulnerability	No. of crop fields	Area (ha)	Percentage (%) area covered (all crop fields)	Percentage (%) of Ward
Low	Low	4	2.39	0.08%	0.02%
	Moderate	268	328.85	10.41%	2.17%
Moderate	Low	15	12.18	0.39%	0.08%
	Moderate	43	274.00	8.67%	1.80%
	High	49	226.68	7.17%	1.49%
High	Moderate	0	0.00	0.00%	0.00%
	High	15	821.97	26.01%	5.41%
Total		**394**	**1666.07**	**52.72%**	**10.97%**

5.6.3 Degradation in abandoned fields

The third and last class in usage status is the abandoned fields, which contituted 37.47% (1183.92 ha) of the total mapped cropped fields area. Table 5.9 shows that a combination of abandoned fields and low degradation was rare. Indicative of this, only 1.22% of the abandoned fields exhibited signs of low degradation (38.66 ha).

As seen in Table 5.9, the gap between total area of abandoned fields that showed moderate and high degradation is relatively small; 512.74 ha and 632.52 ha respectively (43% were moderately degraded and 53% highly degraded). Overall, the majority (632.52 ha) of abandoned fields (1183.92 ha) in the study area were highly degraded.

Table 5.9: Degradation levels in abandoned crop fields

Degradation (Abandoned)	No. of crop fields	Area (ha)	Percentage (%) area covered (all crop fields)	Percentage (%) of Ward
Low	49	38.66	1.22%	0.25%
Moderate	143	512.74	16.23%	3.38%
High	57	632.52	20.02%	4.17%
Total	**249**	**1183.92**	**37.47%**	**7.80%**

Table 5.10 shows that most (36.62 ha out of 38.66 ha) of abandoned fields that exhibited signs of low degradation have moderate vulnerabilty.

Although it’s a small portion of 8.72 ha (1.7% of 512.73 ha), some of the moderately degraded abandoned fields do show a low risk of further erosion. The high risk fields within moderately degraded abandoned fields are however the more dominant, with 278.33 ha (54.28%).

The most detrimental combination of the different categories in the crop fields is the “abandoned, highly degraded and highly vulnerable”. Overall, the majority (632.52 ha) of abandoned fields (1183.92 ha) in the study area were highly degraded and 90% of those were highly vulnerable to future erosion (566.67 ha).

Table 5.10: Vulnerability of abandoned crop fields in different degradation levels

Degradation	**Vulnerability**	**No. of crop fields**	**Area (ha)**	**Percentage (%) area covered (all crop fields)**	**Percentage (%) of Ward**
Low	Low	4	2.04	0.06%	0.01%
	Moderate	45	36.62	1.16%	0.24%
Moderate	Low	11	8.72	0.28%	0.06%
	Moderate	62	225.68	7.14%	1.49%
	High	70	278.33	8.81%	1.83%
High	Moderate	9	65.85	2.08%	0.43%
	High	48	566.67	17.93%	3.73%
Total		**249**	**1183.92**	**37.47%**	**7.80%**

5.6.4 Chi-square statistical test

To assess whether the degradation level in the identified crop fields is significantly related to their usage status, a Chi-Square Test was used through the formulas described in the methods chapter. The observed values in

Table 5.11 were used with the calculated expected values in Table 5.12 to get the test statistic values in Table 5.13.

Table 5.11: The number of identified fields in each degradation and usage class

Observed values				
Degradation	**Used**	**Partly used**	**Abandoned**	**Total**
Low	143	272	49	**464**
Moderate	51	107	143	**301**
High	3	15	57	**75**
Total	**197**	**394**	**249**	840

Table 5.12: The number of expected fields in each degradation and usage class

Expected values				
Degradation	**Used**	**Partly used**	**Abandoned**	**Total**
Low	109.05	218.11	137.84	**465**
Moderate	70.36	140.71	88.93	**300**
High	17.59	35.18	22.23	**75**
Total	**197**	**394**	**249**	840

Table 5.13: The number of identified fields in each degradation and usage class

Chi test			
Degradation	**Used**	**Partly used**	**Abandoned**
Low	10.57	13.32	57.26
Moderate	5.33	8.08	32.88
High	12.10	11.57	54.37

Using the sum of chi test values in Table 5.13, the total chi test statistic value was 205.47.

A significance level of 0.05 with a degree of freedom value of 4 was used to find the critical value. The critical value was found to be 9.49. Therefore, since the Chi-square value exceeds the critical value, we reject the null hypothesis which stated that “there is no significant relation between the usage status and degradation level in crop fields” and accept the alternative hypothesis. Moreover, the p-value was 2.50^{-43} which is lower than 0.05. This also proved that the null hypothesis can be rejected.

Lastly, the Cramer’s V Test was calculated to estimate the relative strength of correlation between degradation and usage status. It was found to be 0.35, which translates to a very strong correlation strength since it is above 0.25.

5.7. Vegetation cover analysis using NDVI

The results displayed in Figure 5.7 display the image analysis using NDVI for the mapped fields in Macubeni.

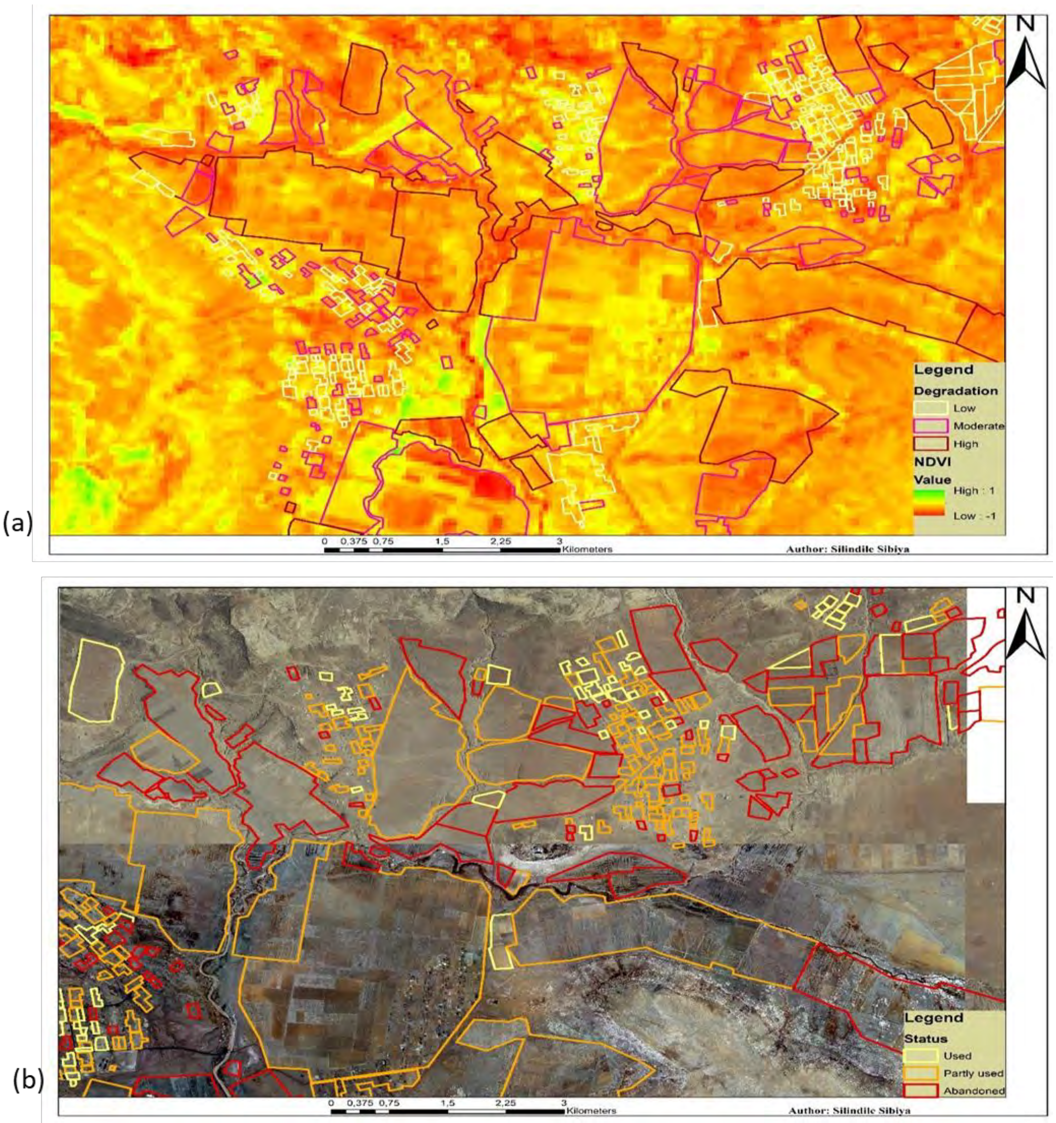


Figure 5.7: (a) NDVI image with degradation classes; (b) Corresponding aerial photo with field usage status

Unfortunately, due to the ArcGIS license conditions held by the researcher at the time of conducting the NDVI analysis, the image reclassification tool was blocked. This means the reclassification method to calculate the total area percentage for different vegetation cover classes could not be executed. However, by using the pixel identifying tool on ArcGIS, it was revealed that the poorly vegetated areas in this case have average NDVI values of 0.122. The poorly vegetated lands as indicated by the reddish colour in Figure 5.7(a) correspond with the high degradation fields and the abandoned fields displayed in Figure 5.7(b).

Moderately degraded fields average an NDVI value of about 0.178 and correspond with most partly used fields. Some portions of the partly used fields indicate good vegetation while others indicate poor vegetation because they are generally mixed in usage status, in that some parts of the polygon may be used, while the rest are not. The low degradation fields have higher NDVI values (0.213) and most of them are used fields.

Chapter 6. Model conceptualisation and interventions

6.1. Introduction

This section describes the conceptual framework of the qualitative model indicating the drivers of crop field abandonment and how they interact in the system.

The range of factors influencing the abandonment of cultivated land illustrates the complexity of the system and thus the need to use systems thinking as a framework for approaching these interconnections. This concurs with the observations that a systems approach to solving complex problems has been increasingly promoted (Turner et al., 2016).

In this study, systems thinking was applied as an approach, where feedback loops were used to assess the interconnections (Sterman, 2001) between land abandonment, degradation, and sustainable land management. Furthermore, a broad category of structured approaches called the Multi criteria analysis (MCA) was used, along with leverage points to assess the different intervention measures. MCA is commonly used within the sustainable development space due to its ability to process complex systems (Pullin et al., 2016). Leverage points are a component of the systems thinking framework to explore relative strengths and weaknesses of interventions in the system (Meadows, 1999).

6.2. The application of Multi criteria analysis

Due to the complexity of environmental conservation, there is a growing need for an application of tools that enable one to have a view of alternative options from different perspectives (Pullin et al., 2016). For individuals or groups to determine their overall preferences from different alternative options, a broad category of structured approaches called the Multi criteria analysis (MCA) is used (Karlson, M. et al., 2016; Zhang et al., 2013; Zia et al., 2011). This approach is commonly used within the sustainable development space due to its ability to process complex systems. For instance, the goal could be to protect vulnerable communities (socio-cultural needs) and protect natural habits (biophysical needs) while also promoting economic growth (economic needs) (Karlson, M. et al., 2016; Zhang et al., 2013; Zia et al., 2011). MCA surpasses Cost-Benefit Analysis (CBA) as it is able to bring structure, transparency and flexibility that CBA lacks (Communities and Local Government [CLG], 2009). However, unlike CBA, MCA fails to exhibit the rationale that benefits should exceed costs (CLG, 2009).

A multi criteria decision analysis (MCDA) also known as Multi-Attribute Decision Analysis (MADA) is within the broader family of MCA approaches. Many have described it as a very effective tool for knowledge synthesis during a decision-making process (Beinat and Nijkamp, 1998; Geneletti and Ferretti, 2015). This is due to that MCDA enables a systematic exploration of the relevant strengths and weaknesses of each option available based on a set of defined criteria explicitly laid out. In doing so, the MCDA reveals how well or poorly the different alternatives perform against the specific requirements (Esmail and Geneletti, 2018). In cases of stakeholder engagements for example, these performances which can be from analytical surveys (i.e., factual information), can be combined with alternatives and preferences of the stakeholders according to what they perceive as priority to them (French et al., 2009). Because MCDA requires a specialised software, it is often used in an analysis where a high level of detail is required, including other additional steps such as sensitivity analyses and pairwise comparisons. MCDA is often used in conjunction with other analytical tools such as GIS (for example, Janssen et al., 2014; Mustajoki et al., 2011). This study applied a simple form of MCA integrated with the spatial analysis and systems diagramming methods.

6.3. Leverage points and interventions

Meadows (Meadows, 1999) defined leverage points as places in a complex system where a slight change made in a specific part results in a big change in the whole system. Therefore, identifying these leverage points in a system is a major step to improving it because they are a place of power (Meadows, 1999). It is also important to place the sustainable land management interventions in places that would cause a big change in the system of drivers of degradation and abandoned fields.

Meadows (1999) listed 12 places to intervene in a system. The points of lowest leverage are not the least important. However, they are often short-term oriented and least likely to cause a significant long-term change in the system (Meadows, 1999). In essence, higher points of leverage in a system tend to have more impacts on future outcomes than the present because they are vision based (Kim, 1999). It is also emphasised in literature that knowing the root causes of a problem makes it easier to deal with and possibly reverse (Nguyen and Bosch, 2013). Therefore, the focus in this study is on drivers of abandoned fields as the root causes of the problem.

Meadows' list of leverage points has been adapted over the years by different studies. In drawing from Meadows' list, Abson et al. (2016) argue that sustainability interventions are too often targeted at places in the system which hold low leverage and thus have very limited potential for transformational change. This is due to the nature of these interventions being of quick fixes to unsustainability instead of ultimate drivers of the system. Therefore, using systems thinking enables one to identify where some of the high leverage points are in the system because it displays the dynamic interrelationships of different components instead of dealing with them in silos (Abson et al., 2016). In this study, we drew from Abson et al. (2016) and Meadows (1999) system characteristics (Figure 6.1).

One of the challenges in sustainability transformational changes is the time scale (Woiwode et al., 2021).This is because it takes time for people to develop personal integrity and change their mental models to bring about something new to their world views.

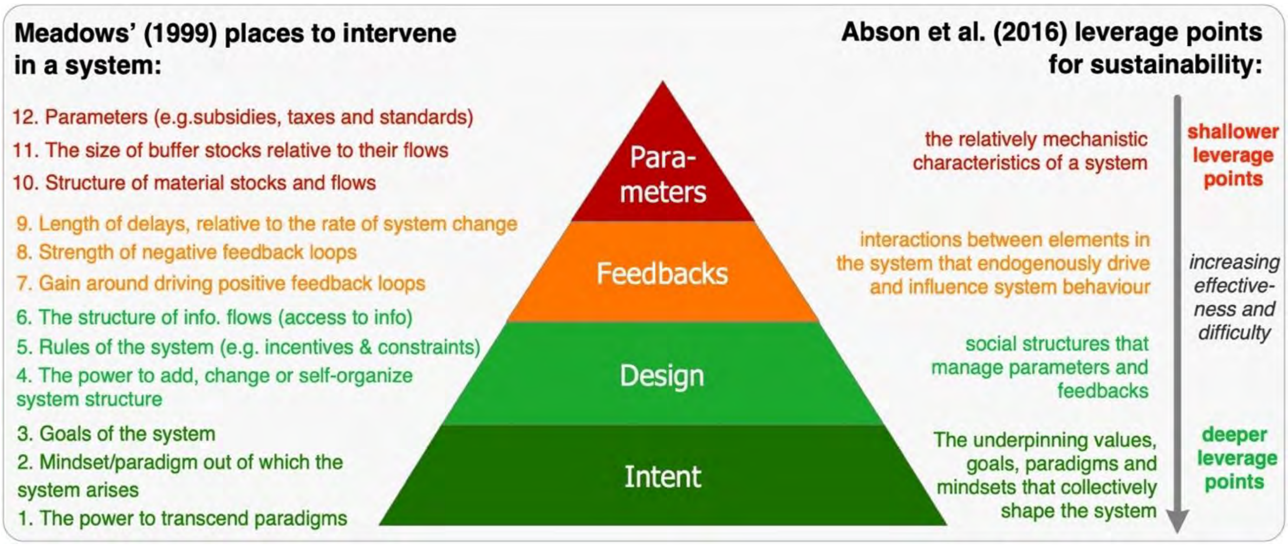


Figure 6.1**:** Visual summary of Meadows' twelve leverage points (left) and Abson et al.'s (2016) reframing of the leverage points as four categories of system characteristics (right). Adapted from Abson et al. (2016) and Meadows (1999).

6.4. Drivers of abandoned lands

This section presents the drivers of abandoned lands via a CLD that is unfolded in three versions (Figure 6.2– Figure 6.4). The versions were created to enable the reader to logically follow the causal loops in increments as they build up and get bigger from version 1 to 3.

The diagramming conventions of CLDs are summarised in Table 6.1.

Table 6.1: Key for the Causal Loop Diagrams

Symbol	Description
$\xrightarrow{+}$	Positive relationship (where a change in the cause results in a change in the effect in the same direction – i.e. an increase in the cause results in an increase in the effect, and vice versa)
$\xrightarrow{-}$	Negative relationship (where a change in the cause results in a change in the effect in the opposite direction – i.e. where an increase in the cause results in a decrease in the effect, and vice versa)
─‖→	Delayed effect
↺ R1	Reinforcing feedback loop (Rn = feedback loop number)
B1 ↻	Balancing feedback loop (Bn = feedback loop number)
$\boxed{\text{stock}}$	Stock variables, which are also called 'levels' in the field of system dynamics (can be anything that accumulates and de-accumulates)

The first CLD (Figure 6.2) introduces the drivers of cropland abandonment. The main stock is abandoned fields, which is influenced mainly by two other stocks, namely land productivity and available labour.

R1 (degradation affecting land productivity): The more abandoned fields there are on land, the more soil structure is disturbed (making it vulnerable to erosion) and remains that way for a long time. The sediment yield increases due to more topsoil being eroded by wind or water. This increases erosion hotspots and promotes gully formation (Huchzermeyer et al., 2018). Having gullies in the landscape increases runoff velocity and volume as water flows collectively through them (Huchzermeyer et al., 2018). This leads to an increased extent of degradation. An increase in the extent of degradation has a negative effect on the land's productivity, which in turn further increases the number of abandoned fields, thus closing the degradation affecting land productivity reinforcing feedback loop.

R2 (land productivity influencing perceptions): Degradation leads to lower plant organic matter inputs into the soil and lower soil fertility (Sepuru and Dube, 2018). Therefore, reduced land productivity results in having low agricultural yield. This feeds back to the negative perceptions of agriculture because it is seen as not being able to generate income and sustain livelihoods (de la Hey and Beinart, 2017; Manyevere et al., 2014). It therefore decreases interest in farming and available labour for working in the fields, leading to more abandoned fields, more disturbed soil structure and even lower land productivity thus closing the reinforcing loop.

Furthermore, most fields in farms are owned by the older generation (age 65+) and have nobody who is younger and willing to take over them (Manyevere et al., 2014). The population group of modernised youth increases the migration rate in the overall population to cities (de la Hey and Beinart, 2017; Manyevere et al., 2014) as they search for employment there. Some people become employed in towns but do not migrate from the village. Therefore, they are time constrained between work in the city and domestic chores, and that leads to more abandoned fields as there is less time to work in the fields (Manyevere et al., 2014). A persistence in the above mentioned urbanisation adds to more negative perceptions of agriculture in villages (it is noteworthy that the positive sign between these two variables on the CLD translates to the same direction effect rather than a positive effect), an increase lack of interest in farming, reduce available labour (de la Hey and Beinart, 2017; Manyevere et al., 2014) and consequently an increase in the number of abandoned fields present.

Whilst it is recognized that there are some other factors influencing available labour (for example, gender dynamics and dependency on social grants), these are excluded from this analysis because the focus is on the endogenous variables.

The likelihood of permanent abandonment is another variable that influences the number of abandoned fields. This refers to the inclination of different community members to resume cultivation again on crop fields that had been previously abandoned or them opting for permanent abandonment. This is captured in Figure 6.2 with the variable 'likelihood of permanent abandonment', which is impacted by three factors. First, if the extent of degradation is high, then the likelihood of permanent abandonment will be high which, in turn, further increases abandoned fields via the reinforcing feedback effects R3 (degradation affecting abandonment). Secondly, the likelihood of permanent abandonment increases along with the negative perceptions of agriculture increasing R4 (perceptions influencing abandonment). Finally, the likelihood of permanent abandonment increases with the duration of abandonment, following the logic that the longer the current field has been abandoned, the greater the existing level of degradation, and therefore the more likely this field is to be permanently abandoned.

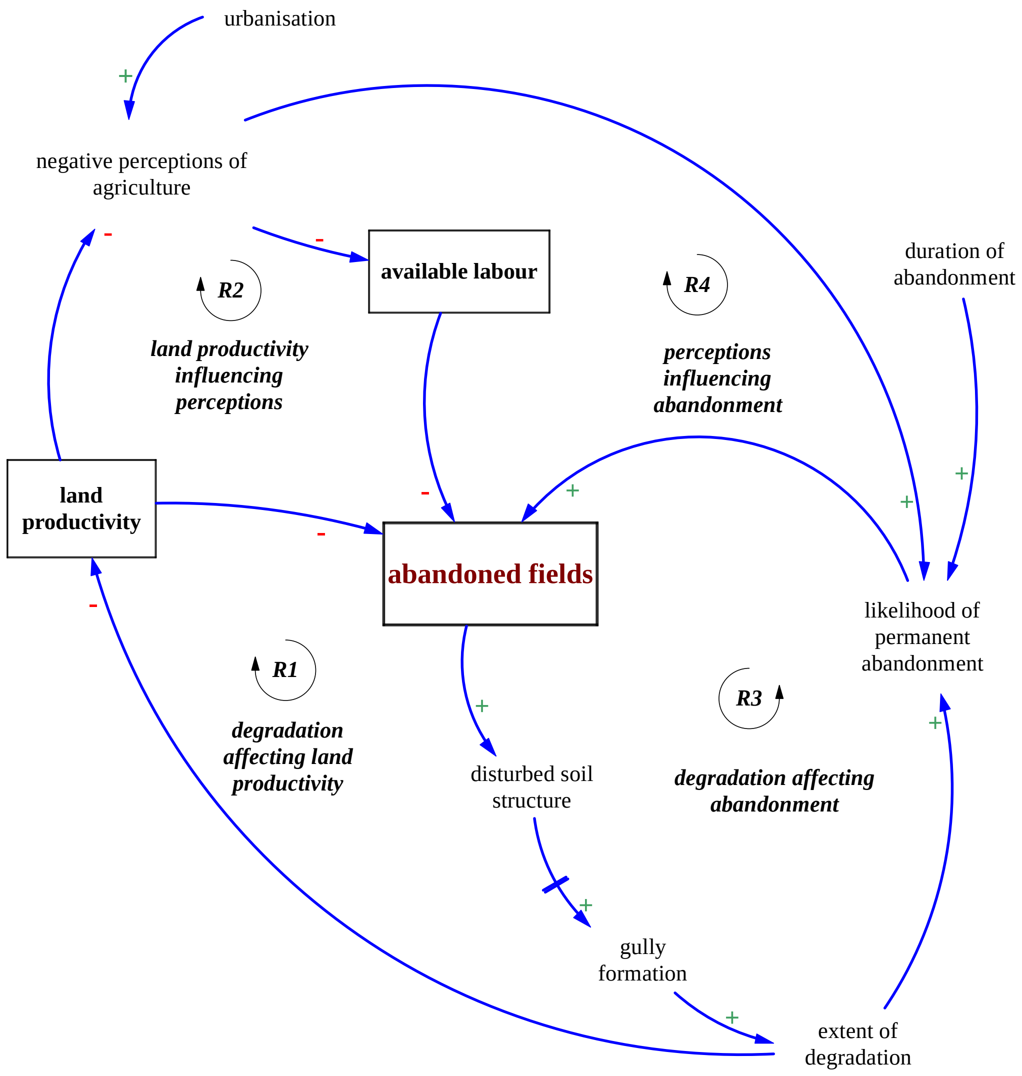


Figure 6.2: Introductory diagram for drivers of abandoned lands (Version 1 of 3 causal loop diagrams (CLDs)) showing three stock variables (in boxes) and four reinforcing (R) feedback loops. See Table 6.1 for full explanations of the diagrammatic conventions.

The second CLD (Figure 6.3) builds on the initial drivers of abandoned lands to show the interactions of three new stocks and their associated variables, and two new feedback loops (R5 and B1). The connections between these new variables are shown via the emboldened arrows.

Income is included in the second CLD as a high-level system output which increases as the three stocks, namely total arable land under cultivation, livestock sales, and land productivity also increase. There is a short-term effect of livestock sales on income. This is because the more livestock sold, the more income generated by farmers, however, other forms of income (more long term) derived from livestock ownership (such as selling of sheep wool) are lost in the process of livestock sales. Capital stock which can be converted into income through future livestock sales is also reduced.

Poor agricultural practices, such as inappropriate cultivation and irrigation, promote poor drainage, which leads to more infiltration and an increased water table level (FAO, 2006). The raised water table increases the concentration of salt content in the soil as evaporation and evapotranspiration takes place, resulting in salinisation, reduced land productivity (Shrivastava and Kumar, 2015). Moreover, the more droughts the area experiences the less available water in the catchment, therefore more crops die (Shrivastava and Kumar, 2015), and land productivity further declines.

The water availability variable considers that the arable land productivity relies on the catchment rainfall levels and so does the maintenance of livestock (through forage). In as much as livestock is high value capital in rural areas (Bahta, 2020), farmers tend to reduce their livestock numbers by increase their selling rates during drought periods to reduce their water and forage requirements (which also increases their income). B1 (livestock number adjustment loop) displays these interconnections. If the number of livestock increases, the food available per animal decreases, which increases the likelihood of overgrazing occurring, which in turn reduces the overall stock of grass cover in the region. As with water availability in relation to livestock watering, livestock sales can also be driven by food stock limitations, which further reduces the overall livestock numbers, and increases the food available per animal in an overall balancing loop (B1).

R5 (overgrazing loop): a growth in livestock results in a reduction of the food available per animal and increases the likelihood of overgrazing, which decreases the grass cover, and further decreases the food available per animal, thus creating a reinforcing overgrazing loop.

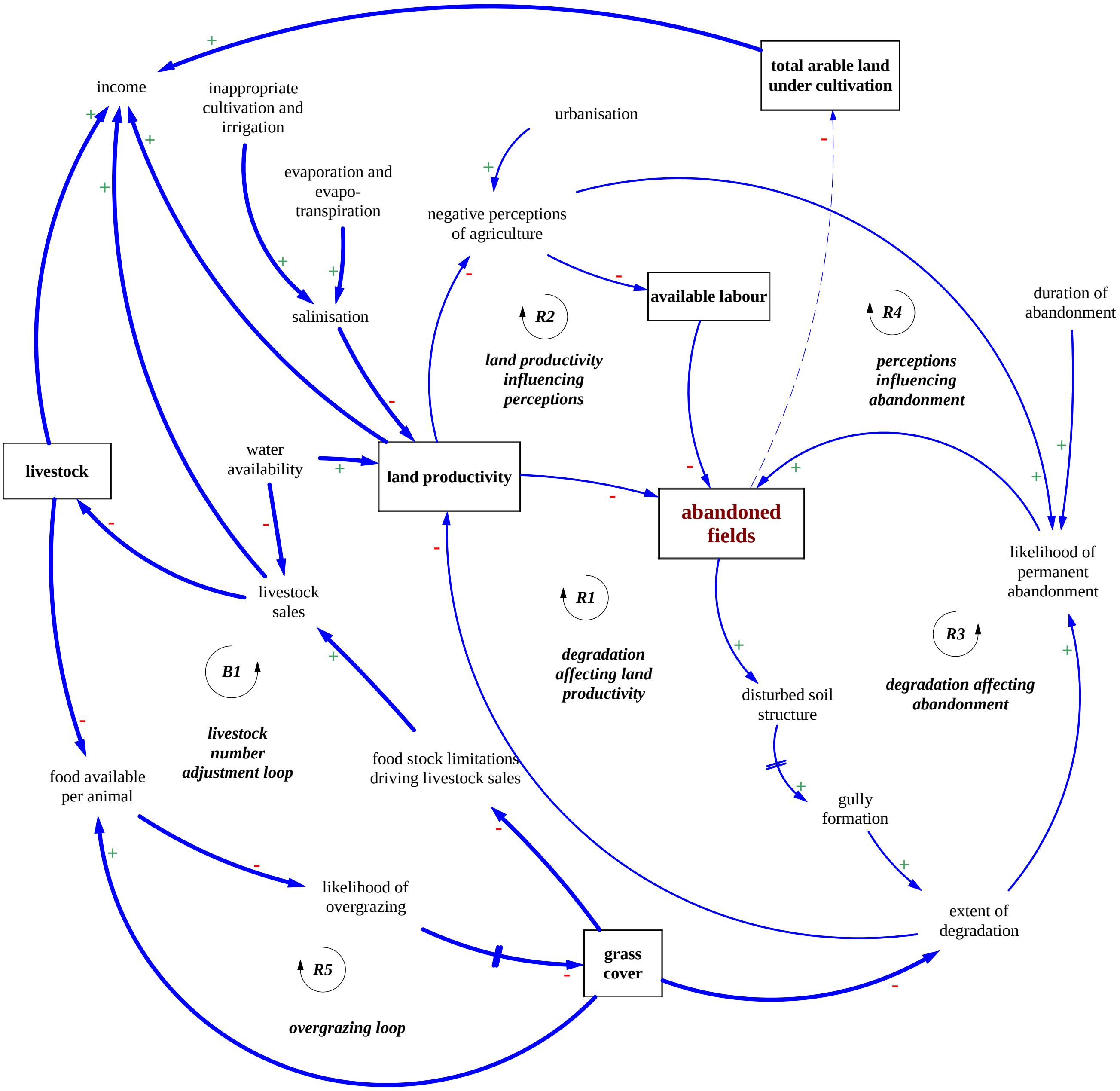


Figure 6.3: Version 2 of three CLDs showing reinforcing loop (R5) and balancing loop (B1), and three new stocks and their associated variables.

The third CLD (Figure 6.4) builds on the earlier two diagrams to show the interactions of five additional feedback loops (R6-R10). Some feedback loops (i.e., reinforcing loop (R5) and balancing loop (B1)) from the previous CLD are excluded from this version to ensure that the diagram remains clear.

The soil function is influenced by a change in organic matter content, and soil nutrient and moisture content, which declines as more topsoil is lost. This decreases the grass cover stock, which further causes a decline in the soil nutrients, thus creating a reinforcing loop R6 (soil functionality). A reduction in grass cover also further perpetuates topsoil, which again reduces soil organic matter and soil function, creating loop R7 (grass cover driving degradation).

With the associated negative impacts on disturbed the soil structure from topsoil loss and abandoned fields, over time the soil becomes susceptible to gully formation. As gully formation is increased, more rainfall flows through the gully channels, which increases the overall velocity and volume of rainfall runoff on the landscape. This further drive topsoil loss and closes the reinforcing feedback loop R8 (gully effect).

R9 (labour affecting security): As the number of abandoned fields increase, the transfer of farming knowledge declines, which reduces potential for land productivity. Moreover, the negative perceptions of agriculture increase, which reduces the available labour in the fields as less people work in the fields. This increases the crime rate due to lack of crowds. The community members have expressed that based on experience, whenever farmers do not go to the fields in big groups, they tend to be more vulnerable to crime acts such as mugging. This therefore further drives abandoned fields as people become reluctant to work in the fields when groups get smaller in numbers.

R10 (indigenous knowledge transfer): As more and more people abandon their crop fields, the transfer of farming knowledge from the older to the younger generation declines (FAO, 2006). This eventually exacerbates the loss of indigenous farming knowledge from the older generation and reduces successful farming. Therefore, the productivity of land is compromised, which ultimately reinforces the abandonment in crop fields.

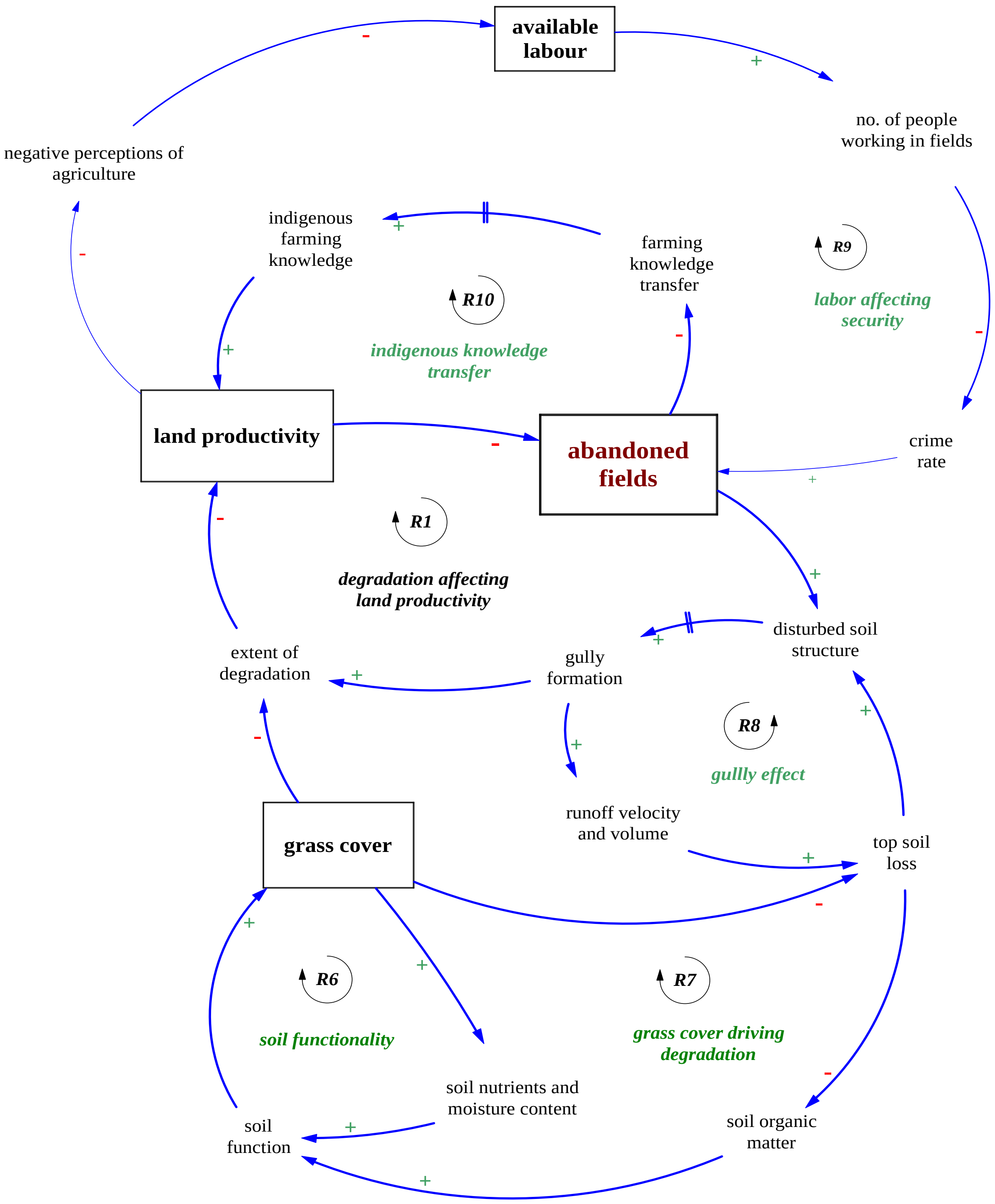


Figure 6.4: Expanded version 3 of the CLD, with the addition of loops R6-R10.

6.5. Assessing interventions using a Multi-Criteria Analysis (MCA)

As noted in the introduction, the GEF5 SLM Project’s activities in the Macubeni catchment are grouped into three hubs: i) the Land Rehabilitation hub; ii) the Livestock and Rangeland Management hub; and iii) the Conservation Agriculture hub. Table 6.2 summarises the interventions in Macubeni that have a direct or indirect relation to abandoned fields.

Table 6.2**:** Summary of the interventions.

Intervention	Description	Associated programme
A. Sediment trapping structures	Reducing sediment yield from rill and gully erosion, using stone lines, brush silt traps and stone packs	GEF5 SLM Land Rehabilitation Hub
B. Climate Smart Agriculture	Improving agricultural adaptation to climate change, including improving tillage practices, increasing soil cover via mulching, and crop rotation in order to increase plant diversity	GEF5 SLM Conservation Agriculture Hub
C. Agrograssing	Revegetating bare patches of land, focusing on gulley heads	GEF5 SLM Land Rehabilitation Hub
D. Grazing management	Shifting from open-access grazing regimes, to using camps & rotational grazing	GEF5 SLM Livestock and Rangeland Management Hub

Table 6.3 to Table 6.5 detail the results from scoring the different interventions against each other through using MCA. There were three criteria used in the MCA:

- Criteria 1 (cost)
  - This was drawn from relevant financial data
- Criteria 2 (reliance on external funding)
  - This acted as a proxy for the relative robustness of each intervention
- Criteria 3 (efficacy)
  - Provided a measure of stakeholders’ perceptions of the impact of an intervention.

The interventions’ scores in relation to their relative cost are summarized in Table 6.3, where the most cost-effective intervention was B. Climate Smart Agriculture, at R305,500, and the most expensive intervention was C. Agrograssing at R1,782,240.

Table 6.3: Summary cost data for Criteria 1 (C.1) of the Multi-Criteria Analysis. All costs in South African Rand (ZAR), calculated on an annual basis. Costs are normalised against the highest cost intervention (C. Agrograssing). Cross-references to Tables A.2-A5 refer to the supporting information in appendices.

Intervention	**Total cost (ZAR)**	**Normalised cost**	**Reference**	**Supporting information**
A. Sediment trapping structures	526,500.00	0.30	GEF5 Project	See Table A.0.2
B. Climate Smart Agriculture	305,500.00	0.17	GEF5 Project	See Table *A.0.3*
C. Agrograssing	1,782,240.00	1.00	GEF5 Project	See Table A.0.4 and Figure A.0.1
D. Grazing management	518,000.00	0.29	GEF5 Project	See Table A.0.5

The results of the interventions' scores in relation to the next two criteria are summarized in Table 6.4. GEF5 project managers were asked during a stakeholder workshop, to rate each of the intervention options in relation to Criteria 2 and Criteria 3. In terms of Criteria 2, the stakeholders rated Intervention B (Climate Smart Agriculture) as being the least reliant upon external funding, with the average score of each of the seven respondents being 2.6, with a normalised score of 0.52. The other three interventions all scored similarly against this criteria, with both Intervention A (sediment trapping structures) and Intervention D (grazing management) having normalised scores of 0.40 and Intervention C (agrograssing) having a slightly higher normalised score of 0.42.

In terms of Criteria 3, the stakeholders rated Intervention D (Grazing management) as having the greatest perceived efficacy, with a normalised score of 0.64. Intervention A (Sediment trapping structures) again ranked last, with a lowest normalised score of 0.46.

Table 6.4: Stakeholder (SH) workshop ratings for Criteria 2 (C.2) and Criteria 3 (C.3) of the MCA. Avg. = average score; Max. = maximum score.

			Stakeholder (SH)							Scores		
Criteria		**Intervention options**	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**Avg. score**	**Top score**	**Norm. score**
How reliant on external funding is this intervention? (5 = no reliance; 1 = completely reliant)	**Reliance on external funding**	A. Sediment trapping structures	1	1	2	3	3	3	1	2.0	5	**0.40**
		B. Climate Smart Agric.	2	3	3	3	2	2	3	2.6	5	**0.52**
		C. Agrograssing	2	2	2	2	3	2	2	2.1	5	**0.42**
		D. Grazing management	2	2	2	4	1	1	2	2.0	5	**0.40**
How effective do you think this intervention will be? (10 = very effective; 0 = completely ineffective)	**Perceived efficacy**	A. Sediment trapping structures	5	5	5	5	2.5	5	5	4.6	10	**0.46**
		B. Climate Smart Agric.	5	5	5	7.5	5	7.5	5	5.7	10	**0.57**
		C. Agrograssing	5	5	5	5	5	7.5	5	5.4	10	**0.54**
		D. Grazing management	5	7.5	5	7.5	5	7.5	7.5	6.4	10	**0.64**

The normalised scores for each of the interventions, in relation to each of the three criteria, were then used as inputs into the MCA Performance Matrix (Table 6.5). As noted with reference to the generic performance matrix (Table 4.3) in the methods section, each criterion is weighted according to perceived relative importance. Criteria 1 (cost) and Criteria 3 (efficacy) are weighted equally to account for 40% of the total score each. Criteria 2 (funding reliance) is weighted at half of the other two criteria (i.e. 20% of the total score) – see the Supplementary Materials for further explanations of the weightings (Appendix A). Given that costs should be preferably lower rather than higher, the direction of the cost criterion is -1, so that the higher the costs, the worse the normalised score. The normalised score is included in Table 6.5 as the performance (Perf.) of each intervention in relation to each criterion. The weighted performance (Wt'd perf.) is then calculated as the product of the score, the weight (Wt), and the direction (hence, for Intervention A. Sediment trapping structures, the normalised score of 0.3 is the performance of Intervention A against Criteria 1 (cost), with the weighted performance of -0.120 being the product of 0.3, 0.4, and -1.

The total scores are the sum of weighted performances. As noted in the final row of Table 6.5, from highest score to lowest, the interventions rank as follows: B. Climate smart agriculture (0.264), D. Grazing management (0.220), A. Sediment trapping structures (0.144), and in last place, C.

Agrograssing (-0.100). The following section synthesizes what these MCA results mean in relation to the systemic and spatial analysis.

Table 6.5: MCA Input Matrix. Perf. = performance; Wt'd perf = weighted performance.

Performance matrix			**Interventions**							
			A. Sed. trapping structures		**B. Climate smart agric.**		**C. Agrograssing**		**D. Grazing management**	
	Wt	**Direction**	**Perf.**	**Wt'd perf.**	**Perf.**	**Wt'd perf.**	**Perf.**	**Wt'd perf.**	**Perf.**	**Wt'd perf.**
C1. Cost	0.4	-1	0.3	-0.120	0.17	-0.068	1	-0.400	0.29	-0.116
C2. Funding reliance	0.2	1	0.4	0.080	0.52	0.104	0.42	0.084	0.4	0.080
C3. Efficacy	0.4	1	0.46	0.184	0.57	0.228	0.54	0.216	0.64	0.256
Total	**1**			**0.144**		**0.264**		**-0.100**		**0.220**

6.6. MCA and Leverage points of interventions

As Meadows (1999) explained, leverage points are places in the system where making a change in would result to a significant change throughout the entire system. It is therefore important for sustainable land management (SLM) interventions to be directed to places that would cause the largest change to the drivers of degradation and field abandonment in a desirable direction. In this research, these places of high leverage were identified through the use of MCA and the leverage points framework by Meadows (1999) and Abson et al. (2016). Although MCA was applied as the quantitative aspect of this analysis, these leverage points remain theoretical in this case as the computerised simulation model was not created. Table 6.6 summarises the MCA ranking for each of the SLM measures, along with their associated levels according to leverage points.

Figure 6.5 visually displays where SLM interventions should be in the system that has been described (according to their leverage). It must be noted that the focus of Figure 6.5 is solely for the display of the different interventions in the system, as the flow of the interconnection of variables was previously described in the unfold of the three CLD versions (Figure 6.2– Figure 6.4).

Table 6.6: Summary of the interventions' performance on the MCA in relation to each intervention's associated leverage point.

Intervention	Ranking on the Multi-Criteria Analysis (MCA)	Associated leverage point (Abson *et al.,* 2016 and Meadows, 1999)
D. Grazing management	2	Point 5: Rules of the System (e.g. incentives & constraints)
B. Climate smart agriculture	1	Point 6: The structure of information flows
C. Agrograssing	4	Point 9: The length of delays relative to the rate of system change
A. Sediment trapping structures	3	Point 10: The structure of material stocks and flows and nodes of intersection

D. Grazing management

For the implementation of grazing management, the community members draft a list of bylaws that everyone needs to agree with and abide by. The process also involves the traditional authorities as it includes penalties that would be imposed on a person for any infringement of the bylaws.

According to the MCA results from stakeholder engagements, there is a high reliance on external funding (thus scoring lower) for the success of this intervention, even though it holds high efficacy. This is due to community members not willing to work on this without payment. However, in terms of the leverage points, grazing management falls within the deepest leverage point (point 5) on the list and ranked highest compared to all the other interventions, which is in the "design" system characteristic. It holds high leverage as it speaks to the rules of the system, the incentives & constraints as indicated by Abson et al. (2016) and Meadows (1999) leverage framework. This intervention tackles community behaviours determined by the set rules and incentives. Because the incentives are direct and clear to all the stakeholders and can be (when there is a desire amongst the people) sustained by the community without external assistance (i.e., government projects), this intervention holds a deep leverage point.

Introducing grazing management into the system (as indicated in Figure 6.5), which includes setting up grazing camps and instilling rotational grazing in the rangelands, will reduce the likelihood of overgrazing thereby increasing the grass cover stock and food available per animal. The more food is available per animal, the less likelihood of overgrazing, which increases the grass stock and ultimately shifting R6 from being a vicious reinforcing loop to a virtuous cycle. The presence of grazing camps enables the community to control the likelihood of overgrazing by livestock through opening certain camps in one season while closing the other for the next season (rotating).

Figure 6.5: Causal loop diagram indicating intervention points in the system (leverage points = highlighted in yellow)

As a result of rotational grazing and resting, the grass in the rested camps grows properly without disturbance, therefore allowing the livestock to have food throughout the year, which reduces the limits that drive livestock sales because farmers often sell their livestock more during food scarcity. The less reason farmers have to sell, the less the livestock sales and the more the livestock. However, maintaining or increasing the number of livestock reduces the food available per animal, which increases the likelihood of overgrazing, driving a decrease in grass cover, which leads to farmers selling livestock in response to food stock limitations. This shows the interaction between the balancing feedback loop B1 and the reinforcing feedback loop R6.

As grass cover is increased, topsoil loss is reduced (as a direct and indirect effect of grazing management), which strengthens the soil structure and minimises the potential for gully formation and effects of rainfall. This stabilises the gully effect loop (R8). An increase in grass cover and a decrease in the formation of gullies both serve to reduce the overall extent of degradation, which positively impacts land productivity (loop R1) and R3 (degradation affecting abandonment). Furthermore, with grazing camps, farmers can avoid the roaming around of livestock which ends up trampling in crop fields. With more control on livestock, farmers can be encouraged to resume cultivation and reduce the crop fields abandonment rate.

B. Climate smart agriculture

According to the MCA results, the highest-ranking intervention is B. Climate smart agriculture. Climate smart agriculture ranked highest in the MCA because it surpassed all the interventions in each of the criteria (see Table 6.3-Table 6.5), thus being the least costly, least reliant on external funding and most impactful amongst all the other interventions.

On the other hand, this intervention fits into the second leverage point (point 6) on the hierarchy list. This leverage point involves restoring or delivering new information into the system, which can drive a change in people’s behaviour (Meadows, 1999). Currently there is a total of 25 garden champions in the pilot villages under the Conservation Agriculture Hub of the GEF5 project (GEF5 SLM, 2020). Therefore, loop R10 (indigenous knowledge transfer) positively changes direction because the presence of garden champions encourages knowledge transfer. This, however, would be a delayed effect as this information is transferred from one part of the catchment to the next. This is including some initial resistance that would come from certain individuals or families that persist in their own ways of doing things and are unwilling to change them. Eventually, as the few people who adopted the sustainable agricultural ways begin to reap visible benefits from this change through in-creased food production, there would a declined resistance from others as more people could start to adopt the same practices.

Climate smart agriculture can also positively affect the land productivity through improving the cultivation and irrigation strategies and decreasing salinisation. This shifts the reinforcing loop R1 (degradation affecting land productivity) from continuously reducing land productivity, to after some time improving it. This can further reduce the negative perceptions of agriculture as people can see the benefits, thus increase interest in farming and decrease the likelihood of abandoning fields. R2 (land productivity influencing perceptions) along with R4 (perceptions influencing abandonment) would then be turned into vitious cycles.

Some CSA practices such as mulching are employed to improve the soil nutrients and moisture content. This benefits the catchment more broadly as soil functionality improves, which increases grass cover (loop R6), reducing the overall extent of degradation in the catchment and feeding into loop R3.

C. Agrograssing

This intervention is ranked third on the leverage points list (point 9), and the worst according to the MCA as it scored an overall performance of 0.016. Agrograssing scored as the most expensive intervention to run as seen earlier in Table 6.3 at R1 782 240.

Agrograssing as an SLM measure aims to improve vegetation cover by planting grass in areas where soil is exposed, and erosion rates are high. Improving grass cover can positively influence R6 (soil functionality) and R7 (grass cover driving degradation) as an increase in grass cover reduces the potential of degradation through minimising topsoil loss and increasing soil organic matter and soil function.

A. Sediment trapping structures

The sediment trapping structures SLM measure comes last on leverage points list, but third on the MCA. The high costs observed in this intervention relate to the employment of 25 residents trained as land conservation activists (LCAs) under the Land Rehabilitation Hub of the GEF5 project in Macubeni who work on these structures continuously on the degraded landscape GEF5. These champions are also supplied with uniforms and tools. Additionally, the perceived efficacy of this intervention was scored low. This is associated with the spatial scale of the work.

Sediment trapping structures are situated further up at leverage point 10 in the table as it involves physical parameters that need to be put on the ground to influence the system by mitigating soil erosion. This intervention for land rehabilitation holds leverage when intersected at the disturbed soil structure variable because that affects the whole gully effect loop R8 by stabilising the soil and reducing runoff velocity. The sediment structures may be stone lines and stone packs built in gullies to stabilise them and silt traps on bare surfaces to trap sediments. The mitigation of soil loss in turn reduces the loss of the organic matter and increase soil function thus grass cover content. This change can also shift both the R1 (degradation affecting land productivity) and R3 (degradation affecting abandonment) loops into virtuous cycles as the extent of degradation driver is remediated.

6.7. Persistent challenges against SLM interventions

Following the assessment of the existing SLM interventions with respect to the dynamics of crop fields abandonment, two persistent challenges are evident in the successful implementation of the interventions.

Persistent challenge 1: the demographic shifts and associated socio-cultural factors affecting land abandonment.

Demographic shifts in Macubeni that affect land abandonment include ongoing urbanisation and a change in the fraction of youth alongside an aging older generation of existing farmers. This urbanisation influences the dynamics of land abandonment through the variable 'negative perceptions of agriculture' (see Figure 6.5). This is a crucial driver of field abandonment via two reinforcing feedback loops: (1) Increasing negative perceptions of agriculture reduce available labour, increasing field abandonment and decreasing land productivity, forming the reinforcing cycle R2 (land productivity influencing perceptions); and (2) increasing negative perceptions of agriculture also increase the likelihood of permanent abandonment, creating reinforcing loop R4 (perceptions influencing abandonment).

At this stage, there are no interventions directly aimed at decreasing the negative perceptions of agriculture. Possible interventions could include directly championing agriculture to the youth. Because it is aimed at sparking and sustaining the interest of the youth in farming, this intervention could serve to shift these three reinforcing feedback loops from their current, undesirable direction (where they are vicious cycles that perpetuate field abandonment and declining land productivity), towards a desirable direction in which decreasing field abandonment and increasing land productivity continually reduces the negative perceptions of agriculture, forming a virtuous cycle.

If championing agriculture to youth SLM measure were to be added into the system, it would fall within multiple leverage points. Firstly, shifting the current dynamic of where field abandonment and land productivity are reinforcing in a vicious cycle, towards having these same dynamics reinforce as a virtuous cycle, addresses point 7 (the 'gain around driving positive [i.e. reinforcing] feedback loops') in the Abson et al. (2016) and Meadows (1999) leverage framework (Figure 6.1). Secondly, directly aiming to address the negative perceptions of agriculture speaks to tackling paradigms and trying to change people's world views, which is positioned at leverage point 2 (intent) as seen on the Abson et al. (2016) and Meadows (Meadows, 1999) leverage framework.

Persistent challenge 2: achieving and maintaining local-level commitment to SLM interventions.

The second persistent challenge is the difficulty of achieving and maintaining local-level commitment to the required SLM interventions on the basis of evident positive change in relation to the scale of the challenges. All development projects operating in historically disadvantaged and underdeveloped areas, like Macubeni in South Africa, are subject to resource constraints where the needs greatly outweigh the available resources. For this reason, areas must be prioritized based on a range of factors including cost, projected benefit, and feasibility (Bullock et al., 2011; UNCCD, 2017b). Specialized fields like Systematic Conservation Planning (SCP) offer methods for maximizing benefits while minimizing costs via spatial prioritization. However, as Strassburg et al. (2019:62) note "…applications of comprehensive SCP approaches to complex large-scale restoration problems with multiple objectives remain sparse". This study's combination of spatial analysis, systems mapping and multi-criteria analysis, drawn together using the synthetic leverage points analysis, can be used to assess different spatial prioritization strategies in a relatively simple way. Two such strategies are discussed here.

Crop fields could be prioritized using the spatial analysis by overlaying the three spatial layers for 'usage status', 'degradation level' and 'vulnerability status'. Strategy A is to prioritize the worst-of-the-worst crop fields that are the largest contributors to degradation by focusing on the fields that are abandoned, with an existing level of degradation ranked as 'high' and with a 'high' vulnerability status for future degradation occurring (see Table 6.7). Figure 6.6a shows the location of these abandoned, highly-degraded, and highly-vulnerable fields in relation to the villages in the region and the GEF5 pilot areas. As an alternative strategy, Strategy B departs from the rationale that it is better to focus on fields that are currently in-use or partly-used, rather than abandoned, because there is more existing investment from the farmers' sides in the used and partly-used fields. Instead of focusing on the fields that are already heavily degraded, Strategy B could focus on fields that are moderately degraded, given that it is often quicker and more cost-effective to rehabilitate a landscape that is only partially degraded rather than one that is in a state of complete ruin (Strassburg et al., 2019). Finally, in order to have some degree of urgency and evidence of why rehabilitation efforts are required, Strategy B could focus on the moderately degraded fields that are rated as 'highly vulnerable' to future degradation. The number of fields meeting these criteria for Strategy B is shown in Table 6.7, with the relative location of these fields in relation to the villages in the region and the GEF5 pilot areas, shown in the map in Figure 6.6b.

Table 6.7 Comparative scenarios for spatial prioritization of interventions.

Usage status	Degradation level	Vulnerability status	No. of crop fields (fields)	Area (ha)	Avg field size (ha/field)	% area covered (all crop fields)
(a) Abandoned	High	High	48	566.67	11.8	17.93
(b) Used + partly-used	Moderate	High	88	328.00	3.7	10.38

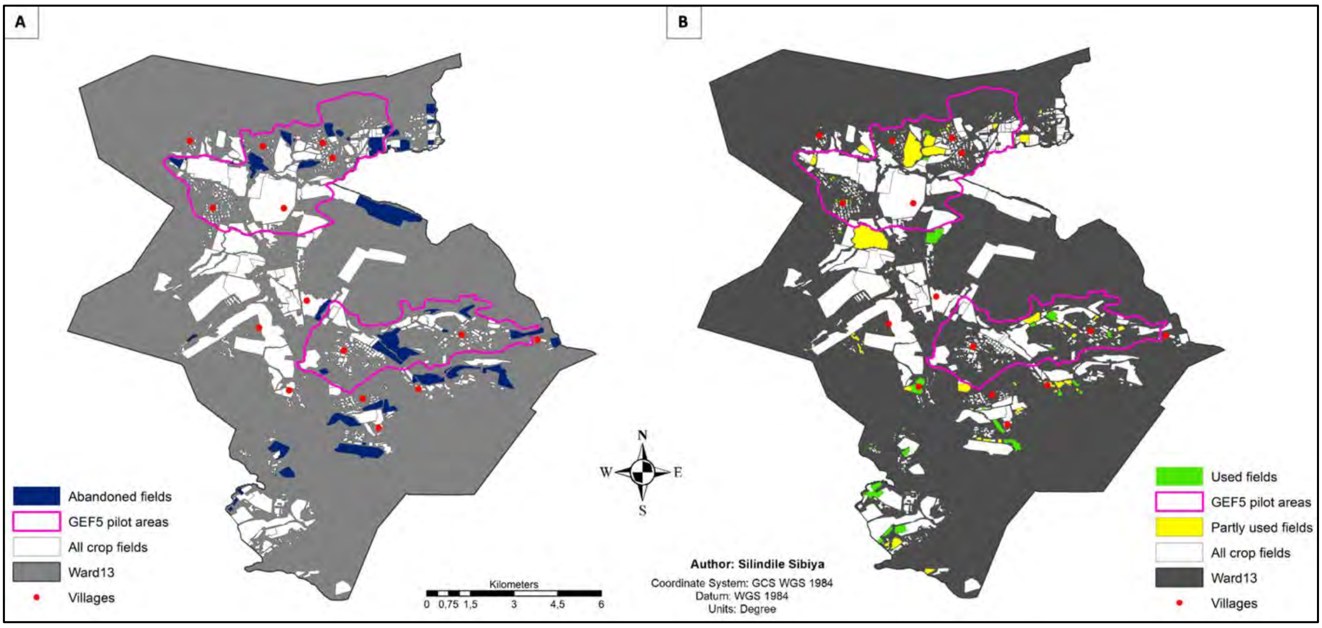


Figure 6.6: A = abandoned fields that are highly degraded and highly-vulnerable; B = crop fields that are used, moderately-degraded and highly-vulnerable, and partly-used, moderately-degraded and highly-vulnerable.

Some immediate differences between the two strategies are evident in Table 6.7. With Strategy A (prioritising the abandoned fields), it would be possible to focus on a small number of fields, most of which are larger on average than the fields prioritized in Strategy B (an average field size of 11.8 ha for the fields meeting the criteria for Strategy A, versus a much smaller average size of 3.7 ha/field for the fields meeting the criteria for Strategy B). This difference favours prioritizing fields as per Strategy A, given that economies of scale could be gained by having a fewer number of larger fields to rehabilitate for which resources could be pooled. Furthermore, focusing on these abandoned, heavily degraded and highly-vulnerable fields (Strategy A) could address almost 80% greater an area covered by all the crop fields than Strategy B (17.93% for abandoned fields, versus 10.38% for used and partly-used). However, by prioritizing the abandoned fields, concerns could be raised that these fields are too damaged already to make rehabilitation economically viable and, given the fields' currently abandoned status, farmers could be less likely to buy-in to rehabilitation efforts.

The alternative strategy of prioritizing used and partly-used fields (i.e. Strategy B) advocates for focusing on interventions on smaller parcels of land in order to benefit from synergistic interactions between the interventions. For example, a combination of agrograssing and sediment trapping structures could be deployed on the fields to control physical soil structure damage via reducing gullies and stabilizing grass cover; grazing management on the surrounding rangelands could then prevent free-moving livestock from exacerbating the existing gullies and from trampling the crop fields; and climate smart agriculture (CSA) practices could increase land productivity in sustainable ways, via increasing water availability and improving soil health via mulching and similar practices. This would also improve soil functionality and soil moisture content and, with improved irrigation practices, help to avoid further soil salinization. The above examples of harnessing the interactions between these interventions would seek to influence leverage point number 7 (the 'gain around driving positive feedback loops') on Meadows' framework (Meadows, 2011). These positive (i.e., reinforcing) feedback loops are evident in Figure 6.5 as follows: agrograssing directly affects the grass cover stock; CSA practices address soil functionality, indirectly affecting the grass stock (loop R6); by reducing overgrazing, grass cover can be managed (loop R5); sediment trapping structures can reduce gullies, stabiliz-ing soil (loop R8) and supporting soil functionality (loops R7 and R6).

Despite these opportunities for positive synergies, focusing the full range of SLM interventions on a smaller number of fields, as advocated for under Strategy B, could face pressure from both external sources (such as the GEF5 funding agency) and internal forces (such as community leaders) to spread the project resources as widely as possible. These pressures can be especially strong when evaluative criteria for a project emphasizes 'number of people affected' rather than 'ecosystem change'. It is also important to recognise that ecosystem recovery time is typically longer than a project time frame: where a project may last 3-7 years, ecosystem recovery of grasslands and wetlands, for example, can run into the decades (Bullock et al., 2011; UNCCD, 2017b). This emphasizes the challenges involved with stakeholders seeing evident change in the landscape from ecosystem restoration and other SLM activities as being a primary motivator to continue performing these activities after the lifespan of a project. Lastly, this points to the importance of Meadows' leverage point 9 (the 'length of delays, relative to the rate of system change').

Chapter 7. Discussion and conclusion

This chapter elaborates on the levels of degradation in crop fields, the drivers of crop fields abandonment and the potential impacts of SLM interventions, as they were investigated in this study. The research objectives listed in Chapter 1 form the core structure of this discussion with respect to the findings presented in chapters 5 and 6. Furthermore, the research questions posed in the introductory chapter are also addressed, along with the limitations of the study.

7.1. Extent of land degradation and usage on crop fields

The degradation of land through detachment and transport of sediment in a catchment can result in numerous negative effects on the ecosystem (Le Roux et al. 2013).Human activities such as crop fields abandonment in communal areas have overtime led to land degradation through gully formation, which further exacerbates soil erosion (Lambin et al., 2001, 2003; Molina et al., 2009). Therefore, a spatial analysis of the cultivated and previously cultivated crop fields in the Macubeni catchment area was conducted to determine their extent of land degradation and levels of vulnerability. Digital aerial photographs data of Ward 13 from 2015 were collected and utilised through GIS tools to achieve this objective.

A total of 840 crop fields in Macubeni Ward 13 were mapped out, covering an area of 3159.95 ha. This was equivalent to 20.81% of the total area in ward 13. The spatial analysis revealed that most of the big fields (more than 10 ha) are located far away from the village homes and close to riverbanks. This can be attributed to the easier access to water supply and the increased soil fertility around the area for optimal planting conditions when the fields were used. However, these fields were also found to be largely abandoned, which could be due to the distance from people's homes, making more and more people opt for not ploughing there but rather in their home gardens. This concurs with several studies (such as Hajdu, 2005; Hebinck et al. 2018; Shackleton et al. 2013; Shackleton and Luckert, 2015; Shackleton, 2018) which found that the overall size of arable land has been decreasing due to big fields being abandoned, while increasing the number of home gardens (which are much smaller is size). De la Hey and Beinart (2017) added that another reason that people abandon their big crop fields is the lack of draught power. They revealed that in the past, people in the community were well equipped to cultivate large areas because they had draught power, and those that did not have oxen were able to rely on their neighbours for assistance, free of charge. More recently, several community members have since abandoned their crop fields due to lack of affordability in hiring oxen for ploughing) (de la Hey and Beinart, 2017). Some communities have expressed that in order for them to resume cultivation in their larger crop fields, they would need external funding and training programs for new farming strategies through government or independent projects (Blair et al. 2018).

7.1.1 An overview of the condition of Macubeni fields

A high level view of the spatial analysis revealed that partly used fields accounted for the largest area coverage of 1666.07 ha, which is 52.72% of all the mapped fields, followed by abandoned fields with 37.47%. Meanwhile, the used fields made up only 9.81% (309.97 ha) of the area. This means that crop fields which were currently being used at the time that the aerial photos were taken, were a minority amongst all the three usage categories. This coincides with the general trend of increasing crop fields abandonment in the Transkei region (Blair et al., 2018) and nationwide (de la Hey and Beinart, 2017; Jewitt et al., 2015). The partly used class having the largest area coverage is justifiable due to it including fields which had a portion that's still in use and a part that had either been abandoned or was being rested at the time.

Furthermore, this study revealed that almost half (47.41%) of the total crop fields were highly degraded (Figure 5.4), and the majority of those were partly used fields, as they accounted for 26.01%, while abandoned fields were 20.02%. This indicates that when fields are actively being used, they do not typically become highly degraded (only 1.38%), compared to the abandoned and partly used fields. This is to be expected because abandoned fields are prone to high runoff and development of degradation features such as rills and gullies as they remain with a disturbed soil structure (Huchzermeyer et al., 2018), especially if the area often experiences drought (Kakembo and Rowntree, 2003). 36.01% (1138.03 ha) of the crop fields exhibited moderate degradation, while fields with low degradation accounted for the smallest total area of 523.73 ha (16.57%). This is irrespective of whether they are used or abandoned.

Just as most fields in Macubeni were identified as highly degraded, the majority (64.52%) of crop fields overall were also classified as highly vulnerable, while low vulnerability fields were only 0.88%. As anticipated, none of the highly degraded fields exhibited moderate vulnerability. This is an expected outcome because the vulnerability of each field to future degradation is highly dependent on the current degradation levels. Therefore, since they are already currently highly degraded, that automatically puts them at a high risk for further degradation, unless there are rehabilitation practices being implemented (i.e., gully stabilisation through stone packing). Otherwise, the concentrated flow of surface water during rainfall events, will keep extending the steep headcuts on gullies as it flows through the channel and creates a waterfall and plunge pool that weakens the backwall (Bull and Kirkby, 1997; Mararakanye and Le Roux, 2012). This process will continue upslope until the headcut reaches a point the soil is too shallow and the underlying bedrock is resistant to erosion (Rowntree, 2016).

Another indicator of degradation vulnerability that was utilised is the presence of bush encroachment through expansive species such as *Euryops floribundus* (Mucina and Rutherford, 2006) or Lapesi as commonly referred to by the local community. Cramer et al. (2008) argued that the susceptibility of bush encroachment when fields are abandoned becomes relatively high. However, 95.71% of all the crop fields in Macubeni exhibited little to no encroachment (Figure 5.7). This was a clear indication that the encroachment factor was not a good indicator to use for degraded crop fields in this case as it only occurred on them in very rare cases. Therefore, this class was rendered insignificant for crop fields degradation assessment in this study. It does however, as echoed by Beyene et al. (2014), Gxasheka et al. (2019) and Molepo et al. (2017) remain vital for overall catchment assessment and especially on rangelands, which then affects the general soil quality through nutrient depletion in the area.

Moreover, only 1.2% of the abandoned fields exhibited signs of low degradation and 0.06% with low vulnerability. In instances where this occurs, it is often the abandoned areas that have been in the state of abandonment for several years (decades) and have naturally self-rehabilitated as vegetation cover started improving on the surface instead of the typical route where degradation keeps progressing (Harvey, 2001). Fryirs and Brierley (1999) and López-vicente et al. (2013) affirmed that this is the period after sediment yield peak from that abandoned space has been reached and normalises as the vegetation recovers. This however can only take place if the topsoil was not completely stripped off during the peak of soil erosion, in which case it turns the fields into “erosion hotspots”, thus inhibiting recovery and intensifying degradation further (Kakembo and Rowntree, 2003).

7.1.2 Degradation and vulnerability in fields

About half of the used fields area (153.84 ha of 309.97ha) exhibited signs of low degradation (Table 5.6). 98% of the used fields that had low levels of degradation have moderate vulnerability to future erosion. This is because even though there are no erosion features exhibited by these fields, they still have a level of exposure to future erosion due to the exposed soil surface when it is cultivated (Huchzermeyer et al., 2018). Used fields that were classified as moderately degraded were mostly (39 fields out of 50) highly vulnerable to future erosion. This is because the potential for the already evident (although moderate) degradation in and around these fields to develop further, is increased.

Only 14% of the used fields were highly degraded, and as anticipated, also highly vulnerable. The highly degraded used fields are a rare occurrence where the fields are actively used but have erosion features such as gullies on them. An observation made from the aerial photos analysis of the study area is that most of these used fields in the high degradation class are in immediate vicinity of larger gullies and steep slopes. It can therefore be deduced that as those gullies created channels for high velocity runoff, they developed further and cut their way into the nearby crop fields, thus creating high levels of degradation even though the fields are in use.

Furthermore, this study found that the partly used fields category is not only the largest with 1666.07 ha in total, but it also consists of the largest area (821.97 ha) of highly degraded and highly vulnerable fields (49.34% of the partly used fields). Abandoned and highly degraded fields followed closely with 632.52 ha (53%). This means that a vast majority of the Macubeni crop fields are highly degraded and highly vulnerable, further echoing the claims by Blair et al. (2018), de la Hey and Beinar (2017) Jewitt et al. (2015) that degraded and abandoned fields are increasing in South Africa.

7.1.3 An application of the Chi-Square Test of independence

A Chi-Square Test of independence was applied to determine the significance level in the relationship between the usage status and degradation extent in crop fields. The calculated Chi-square value of 205.47 exceeded the critical value of 9.49, therefore the null hypothesis (H_0) which stated "there is no significant relation between the usage status and degradation level in crop fields" was rejected to accept the alternative hypothesis. The alternative hypothesis (H_1) stated that there is a significant relation between usage status and degradation level in crop fields. Equally, the p-value of 2.50^{-43} was also below the 0.05 significance level, further substantiating that there is a significant relation between the usage status and degradation level in crop fields. Lastly, the Cramer's V Test calculated was 0.35, which also confirms that there is a very strong positive correlation strength between degradation and usage status as this value is above 0.25.

This hypothesis test concurs with the claims made by several studies (Hebinck et al., 2018; Huchzermeyer et al., 2018; Le Roux, 2011; Parwada and Van Tol, 2016; Valentin et al., 2005) that the usage status of fields, such as those which are abandoned, are in close association with the levels of degradation observed in croplands due to factors such as lack of vegetation cover and high sediment yield.

7.1.4 Vegetation growth viguor

To assess the overall vegetation vigour, an image analysis was conducted using NDVI for different degradation classes and usage status, where values closer to -1 indicate poor to no vegetation, while those which are closer to 1 are indicative of high photosynthetic activity, thus good vegetation cover (Dalu et al., 2013).

It revealed that poorly vegetated areas have an average NDVI value of 0.122. It was further revealed that the highly degraded fields and the abandoned fields on the map corresponded with land spaces classified as poorly vegetated, which makes the assigned degradation classes suitable because abandoned fields are expected to have poor vegetation growth vigour (Huchzermeyer et al., 2018). Moreover, fields with an average NDVI value of 0.178 were found to be mostly the partly used as some parts of the partly used fields would have good vegetation cover, while others do not. These fields were also moderately degraded.

Higher NDVI values such as 0.213 were exhibited by fields that displayed signs of low degradation and currently used status. This is interesting because the used fields are the ones that often have exposed soil (little to no vegetation). However, in this case study, the higher NDVI values on used fields may be attributed to that the satellite image used in this analysis was taken in summer, where fields don’t appear as cultivated at that moment, thus consisting of some vegetation cover.

7.2. Looking at the drivers of abandoned lands systemically

After determining the degradation levels of crop fields through spatial analysis, CLDs enabled an assessment of the complex relationships between different drivers of abandoned fields, with both their positive and negative feedback structures and simulations of future trends (Vafa-arani et al., 2014), thus providing a holistic view of the problem (Itzkin et al., 2021). This approach has been applied in the neighbouring Tsitsa catchment (i.e., Itzkin et al., 2021), which also makes it suitable here because the two catchments have similar settings in respect to physical environmental attributes and social aspects. However, the similar studies in neighbouring catchments do not use a systems approach to explore the degradation dynamics on crop agricultural lands as done in this research.

As the literature revealed in this study, there are various factors that drive field abandonment. These may be natural environmental factors (e.g., erosion and reduced soil quality), socio-economic (e.g., land productivity and poor agricultural practices), and social (negative perceptions of agriculture and availability of labour) (Blair et al., 2018; de la Hey and Beinart, 2017; FAO, 2006; Manyevere et al., 2014). This shows the value of using a system-oriented approach because many drivers of field abandonment act on the system simultaneously with multiple interactions. Furthermore, Banson et al. (2014) and Liu et al. (2015) concur by arguing that there are several sustainability actions that are implemented through systems thinking that would not have been possible with a conventional approach. In light of this, the use of CLDs detailing the interaction of drivers, also exposed points of leverage where interventions for sustainable land management can be best implemented.

7.3. An integration of the spatial analysis, MCA and systems thinking

As emphasised by Abson et al. (2016), leverage points in a system are not independent of each other, and the application of one can result in complex and unexpected changes. This concurs with Newell (2012) stating the importance of a holistic view of the problem prior to attempting to solve it.

Due to the spatial analysis reporting that abandoned highly degraded fields occupy a large area of 566.67 ha, therefore seemingly the best place to start rehabilitation, it would not be the case with respect to impact and value for the local community. Moderately degraded fields were identified as a better target for rehabilitation efforts compared to the already severely degraded. As displayed in Figure 6.6, the intervention areas are the fields which are currently being used (people are actively farming on them) and some partly used but have a high-risk potential to future erosion (covering 3.21% and 7.17% out of all the mapped fields respectively). Most of these subject fields are also closer to the village areas, therefore adding incentive for rehabilitation as they are easily accessible. Rehabilitating them would result in people seeing the positive changes and thus become motivated to carry out these interventions in the future without external resources. This demonstrates value at the highest leverage point with as few resources for implementation as possible because the degradation levels of these fields have not yet reached the worst-case condition of being abandoned and highly degraded.

An emphasis on opting for the use of minimal resources is applied by the MCA analysis which revealed a high reliance of the SLM interventions on external resources. Moreover, external resources such as the GEF5 project often have limited funds, therefore they need to be maximised as much as possible through prioritization. Therefore, the spatial analysis of crop fields informed the target areas for SLM interventions and where they could be most effective. Such strategies have also been used previously in other areas such as Maclear, which is similar to this project area through the Tsitsa project funded by the DFFE. Ultimately, this is to show how a combination of all these critical tools can be used to inform impactful decisions by different stakeholders in respect to the environment and people.

7.4. A Multi Criteria Analysis and leverage points synthesis

According to the MCA results, the interventions rank from highest score to lowest as follows: B. Climate smart agriculture (0.264), D. Grazing management (0.220), A. Sediment trapping structures (0.144), and in last place, C. Agrograssing (-0.100). The interventions rank on the MCA almost coincide with the leverage points framework of Abson et al. (2016) and Meadows (1999) as what comes first on the MCA comes second on the leverage points hierarchy or vice versa.

“Grazing management” is ranked highest on the leverage points hierarchy because it tackles community behaviour and has benefits at much bigger scale socially, environmentally, and financially. Socially, community members work together through bi-laws they have put in place to keep the grazing management in order (although they tend to not feel inclined to hold each other accountable for anything that goes against the set bi-laws). Environmentally, the proper management of the grazing in the area promotes grass cover and overall condition of the rangelands (Bunning et al., 2011; Scholes, 2009) as some areas of the land are rested for a certain period, thus avoiding overgrazing and land degradation. This also means there are little to no livestock roaming around the crop fields trampling and destroying fences and crops, which have contributed to people abandoning their crop fields. Financially, as the condition of rangelands increases, livestock numbers and quality also increase. Therefore, this enables livestock owners to make more money from the sales locally and externally through auctions.

The MCA however, ranked the grazing management intervention second because as much as the theoretically, this intervention can be sustained by the community without external assistance, the trend in the catchment when this analysis was done, revealed that the community members were not willing to manage this intervention independently. Although the GEF5 project made it abundantly clear on several occasions that this is done to directly benefit them as a community, there were still high expectations of payments from the GEF5 project for them to carry out the work. Therefore, this means as soon as there is no form of payment received, people will not want to work anymore, thus leaving the whole thing to a collapse since the is no desire. As stated by Fischer and Riechers (2019) when the desire for change in the society is aligned with practical means to implement measures, then trans-formations are possible, and paradigms can be shifted.

“Climate smart agriculture” was scored the second highest on leverage points hierarchy while it was highest in overall performance in the MCA. This could be attributed to the MCA using costs, the reliance on funding and efficacy to determine the ranking. Climate smart agriculture is the least costly to implement and needs very little external funding to sustain, but very impactful locally as people have a direct gain from this intervention, which they can also see in short term. The implementation of this intervention however may be challenging based on the past experiences as raised during stakeholder engagements. The GEF5 Project was able to implement this intervention before under the conservation agriculture project hub. It unfortunately collapsed within a short space of time due to payment issues. This was despite the GEF5 Project team having explicitly expressed to the community at the beginning and during the course project that there would be no payments offered for this activity as it had direct benefits to them (i.e., getting vegetables for their families). Therefore, the success of this intervention also becomes heavily reliant on external funds because the youth is not willing to work on crop fields without payment

“Agrograssing” was positioned at leverage point 9 on the hierarchy of leverage points and scored lower (fourth place) on the MCA. This is because the agrograssing intervention occurs at a much smaller scale relative to the catchment area and how much space can be successfully rehabilitated in this process at the current rate. There are also difficulties surrounding the successful implementation of this intervention such as roaming livestock grazing on the grass at an early stage of its growth (if seeds were used). This integrates with the Livestock and Rangeland Management Hub’s intervention because if implemented successfully, activities such as rotational grazing would aid in reducing the likelihood of livestock grazing on the grass in early growth stages in rangelands and minimise grazing on crop fields. This is because there would be more control on the livestock movements within the catchment, thus allowing agrograssing to thrive and encourage more integrated and holistic land management (Schwilch et al., 2014). Another challenge is the slow process of planting and selling of vetiver grass. The costs incurred for the effective implementation of agrograssing at a large scale would be high if it is through the purchase of vetiver grass slips from other catchments. Therefore, the length of delays relative to the rate of change in the system are longer.

The “sediment trapping structures” intervention also has high costs and would not be sustainable without external funding because the same issues of payment expectations existing in the other hubs persist in this hub as well. In as much as the actual structures have zero costs because they make use of rocks found in the area, none of the trained local land conservation activists are willing to continue the work without getting paid. Although this rehabilitation strategy of stabilising gullies and putting silt traps on eroded soil is beneficial to the catchment environment (especially for livestock), the people do not perceive this as a direct benefit to them. Hence, again, the expectation of remunerations from the GEF5 Project. This would also need to be adopted at a bigger spatial scale (more buy in from the community at large) to make a significant impact on the catchment rehabilitation.

Literature revealed that there are several sources of resistance against the proposed interventions aimed at improving peoples’ perceptions of agriculture. These include the overall strengthening of rural-urban connections (Hebinck et al., 2018), increasing diversity in household incomes, along with declining dependency on agriculture for income (Twyman et al., 2004), changes to agrarian identifies (Hebinck et al., 2018), and broader factors of globalization and modernization (Shackleton and

Luckert, 2015). Taken collectively, these sources of change resistance show why this particular challenge is likely to remain persistently problematic in the way in which it will continue to drive land abandonment and, in turn, degradation.

This study has also illustrated both the requirement for, and the complexities involved in, spatial prioritization. Prioritization can lead to increases in efficiency (for example, in a large-scale analysis of rehabilitation in the Brazilian Atlantic Forest, Strassburg et al. (2019) showed how strategic prioritization can triple the conservation gains while halving the costs). One of the main factors we considered in our prioritization strategies was whether to focus on heavily degraded or moderately degraded fields. The systemic analysis of the associated feedback loops supports Strassburg et al.'s (2019) argument that as degradation proceeds, more ecosystem benefits are lost, with the degree of loss of individual benefits increasing. The reinforcing (vicious) cycles continue to drive the system in a destructive direction, toward poorer land productivity, increased land abandonment, and increased degradation. All of these factors mean that self-recovery (i.e. recovery without interventions) will be slower and the impact of external interventions (such as those driven by the GEF5 SLM project) will be reduced.

7.5. Limitations of the study

Due to resource constraints, the system dynamics modelling component of this study did not progress beyond the model conceptualisation stage, i.e., qualitative modelling using causal loop diagrams (CLDs). As noted by Sterman (2001), one of the biggest shortfalls of CLDs is that the details of change such as amplitude/intensity within a system are not captured. However, system dynamics modellers have often affirmed that CLDs are the foundation of developing a dynamic hypothesis, therefore providing an insightful interpretation of the system's endogenous dynamics of the problem (Turner et al., 2016), which is a vital step.

A limitation on the conceptual model of SLM interventions and their respective impacts or successful implementation in the system is that it is based on several assumptions. One assumption for instance is that the trainings provided by the GEF5 Project will be expanded by the trained individuals in the community to pass on the learned skills to the rest of the people and create a self-sustainable culture of knowledge sharing for the betterment of the community at large (without external assistance). Another assumption is that there will be a desire and effort from the traditional leaders to keep open communication channels with the local municipalities to receive assistance where applicable, such as with getting seedlings for gardening (affecting the impact of climate smart agriculture intervention) and receiving strategical advice for livestock management (affecting the grazing management intervention). Therefore, the leverage points of these interventions could be reduced as people get discouraged and the interventions are not sustained.

Furthermore, the satellite images such as those from Sentinel and Landsat which were more recently updated (2020) compared to the aerial photos, could not be used for mapping because a higher pixel quality was required to map the crop fields as accurately as possible. This led to the use of older photographs (from 2015) however, these had a much greater pixel quality, which was appropriate for the purpose of this study. Additionally, not having recently updated satellite images of the study area beyond 2015 and the type of mapping method that was applied (time intensive), in conjunction with the allotted time for this research, also restricted the potential of investigating the spatial changes over time. This would have matched the dynamic hypothesis presented by the mapped causal loop diagrams.

Lastly, another limitation was that the license conditions of the ArcGIS software held by the researcher at the time that this study was conducted, did not allow for image reclassification during an NDVI analysis. This tool would have enabled the calculation of total area percentage under various vegetation cover classes, therefore creating limitations of the vegetation growth vigour analysis. However, since this was not the primary tool for assessment, the available image analysis sufficed.

7.6. Recommendations for future research

There are benefits and downfalls of using a qualitative model versus a quantitative one. Using CLDs to assess the interaction of different feedback loops in the system is useful as a qualitative model because it enables the communication of people's mental models and visually displaying the different behaviors that may be exhibited by a system. However, it would be recommended to take it further and be able to use values in the system (quantitative modelling), as one can make use of stock and flow tools in systems modelling. Quantitative modelling assists in stretching the time looking into future scenarios and the possible solutions of some of the elements in the system. It also enables the researcher to go back into the past from a few years to see the trends in changes. For example, the impact of different SLM interventions can be tested by altering certain drivers in the system to see how it reacts.

A combination of the two (qualitative and quantitative modelling) methods also strengthens the representation of a study's findings. Furthermore, interventions can be tested under a range of scenarios to experiment with combinations of interventions that offer the most robust outcomes. To this end, the next stage of this research could be to develop a quantitative simulation model. Amongst other aspects, this quantitative model could support analysis of the temporal dimensions raised in this study, including: (a) the ecosystem recovery times associated with the interventions, which, if modelled quantitatively, could be assessed against a baseline 'self-recovery' period; and (b) the hypothesis that highly degraded fields have been abandoned for longer periods than others because, as per Koulouri and Giourga (2007), longer periods of field abandonment (measured in years to decades) are associated with an intensification of soil erosion and gullies. The time associated with the fields' abandonment was excluded from the analysis, but could be part of a future study.

The value of including the Multi-Criteria Analysis (MCA) in this study lay in the way in which the different interventions assessed in the paper could be compared against one another, simultaneously considering economic, environmental, social, and technological aspects (Kurka and Blackwood, 2013). The MCA was also used as a way of structuring stakeholder input, using qualitative variables (such as stakeholders' perceptions of efficacy) along-side quantitative variables (the financial costs of the interventions). A limitation of MCA is that it cannot show that an action adds more welfare than it detracts. In this respect, MCA is inferior to alternative approaches, such as Cost Benefit Analysis (CBA), given that the former contains no explicit rationale that benefits should exceed costs (Dodgson et al., 2009; Dobes and Bennett, 2009). For this reason, some scholars recommend caution in the use of MCA for policy formulation and policy analysis (World Weather, 2021). Future studies could benefit from a greater inclusion of analyses that account for relative costs and benefits of both acting and not acting (for example, by including the costs of not intervening in the landscape, which were not calculated in this study).

7.7. Conclusion

There has been an increase in crop fields abandonment in the Transkei region of Eastern Cape South Africa (Blair et al., 2018). On South African landscapes, soil loss is 8 to 30 times faster than soil formation (Seutloali et al., 2017), which leads to poor soil quality. SLM measures are aimed at enhancing the productivity and protection of natural resources, while being economically viable and socially acceptable (Schwilch et al., 2014), by encouraging an integrated and holistic perspective of land management (Liniger et al., 1999; Schwilch et al., 2014). However, the effectiveness of SLM in the context of the various factors that affects their success or failure is not well researched.

The purpose of this study was to investigate the degradation levels exhibited by crop fields in Macubeni, and the potential impact of SLM interventions on mitigating drivers of land abandonment. A multi-method approach was followed to achieve this goal; a) mapping the crop fields according to their usage and degradation levels, b) undertaking a literature review and conduct stakeholder engagements to understand abandoned fields drivers and their relationship with degradation, c) systems diagramming, d) conduct a Multi-Criteria Analysis (MCA) of the interventions undertaken in the study site in relation to abandoned fields. In doing so, the findings were as follows:

- The bigger crop fields located far away from the village areas are mostly abandoned and highly degraded amongst all the other fields. This concurs with the notion that arable lands being used are decreasing in size due to the big fields being abandoned more than the smaller home gardens (Hajdu, 2005; Hebinck et al. 2018; Shackleton et al. 2013; Shackleton and Luckert, 2015; Shackleton, 2018).
- Most (52.72%) of the crop fields in Macubeni are partly used, followed by abandoned fields with 37.47%.
- The majority (47.41%) of the total crop fields were classified as highly degraded and most of which were partly used fields, followed by abandoned fields. This hinders the optimal benefits of livelihoods and ecosystem services.
- Bush encroachment on crop fields is not as common as it is on rangelands, as shown by the 95.71% of all the crop fields that exhibited little to no encroachment.
- There is a strong significant relationship between the usage status and degradation level in crop fields.
- The various attributes that drive field abandonment include natural environmental factors, socio-economic and social (Blair et al., 2018; de la Hey and Beinart, 2017; FAO, 2006; Manyevere et al., 2014).
- Grazing management and Climate smart agriculture are interventions with the highest leverage points in the system of land abandonment drivers.
- The innovative multi-method approach applied in this study can provide a holistic, dynamic, and integrated decision-support to land conservation and rehabilitation projects in similar settings across South Africa and other developing countries as opposed to the more traditional one-dimensional approach.
- Based on the assessed potential impacts of the interventions implemented by the GEF5 project in Macubeni as revealed by the CLDs, leverage points framework and MCA, these SLM measures have a great potential to tackle the dynamics of land abandonment at a root cause (rather than symptomatic) level. However, there is a need to first shift the community’s mental models to alleviate the currently existing resistance emanating from factors such as financial benefits, how agriculture is perceived, and the progressing demographical shifts.

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Appendices

Appendix A - Multi Criteria Analysis

Overview

Supporting information for the multi-criteria analysis (MCA) is presented here as follows:

Section A.1: Data, calculations, and associated references for Criteria 1 (cost) – see Table A.0.1, which provides high-level cost data with cross-references to the associated breakdowns for the cost of each intervention (detailed in Table A.0.2-Table A.0.5and Figure A.0.1).

Section A.1: Data, calculations, and associated references for Criteria 1 (cost)

Table A.0.1: High-level cost data (for Criteria 1 (C.1)). All costs in South African Rand (ZAR).

Intervention	Total cost (ZAR)	Normalised cost	Reference	Comments
A. Sediment trapping structures	526,500.00	0.30	GEF5 Project	See Table A.0.2
B. Climate Smart Agriculture	305,500.00	0.17	GEF5 Project	See Table *A.0.3*
C. Agrograssing	1,782,240.00	1.00	GEF5 Project	See Table A.0.4 and Figure A.0.1
D. Grazing management	518,000.00	0.29	GEF5 Project	See Table A.0.5

Table A.0.2: Intervention A: sediment trapping structures, focusing on soil erosion control.

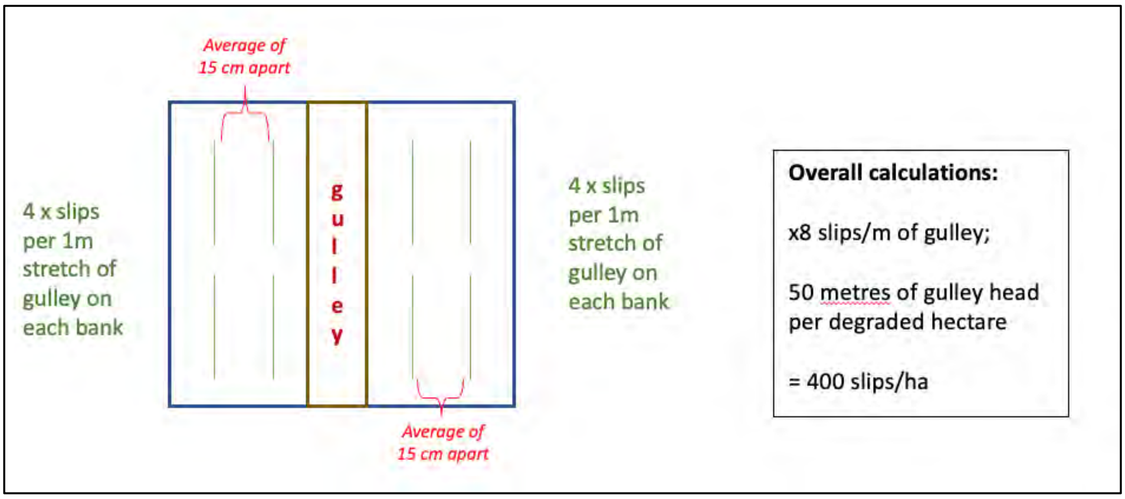
Sediment trapping structures (focus on soil erosion control)				
Item	**Unit cost**	**Quantity**	**Cost**	**Comments**
Uniforms	1,400.00	50	70,000.00	Two uniforms are bought per LCA each year (hence 25*2 = 50)
Wages	820.00	300	246,000.00	25 LCA's, each paid R820/month, for 12 months
Tools	1,420.00	25	35,500.00	Tools include wheelbarrows, spades, and picks
Tanks and installation	7,000.00	25	175,000.00	Tank = R5,000; installation = R2,000, total = R7,000
Total			**526,500.00**	

Table A.0.3: Intervention B: climate smart agriculture (CSA).

Climate smart agriculture				
Item	**Unit cost**	**Quantity**	**Cost**	**Comments**
Uniforms	1,400.00	50	70,000.00	Two uniforms are bought per LCA each year (hence 25*2 = 50)
Seeds	15,000	1	15,000.00	
Seedlings	10,000	1	10,000.00	
Tools	1,420.00	25	35,500.00	Tools include wheelbarrows, spades, and picks
Tanks and installation	7,000.00	25	175,000.00	Tank = R5,000; installation = R2,000, total = R7,000
Total			**305,500.00**	

Table A.0.4: Intervention C: agrograssing

Agrograssing		
Variable	**Quantity**	**Unit**
Cultivated lands hectares (Ward 13)	3160	ha
percentage crop fields heavily degraded	47	%
heavily degraded	1485.2	ha
required per degraded hectare	400	slips/ha (*see Figure A.1*)
total slips required	594080	slips
cost/slip	3.00	ZAR/slip
total costs	1,782,240.00	ZAR



Overall calculations:

x8 slips/m of gulley;

50 metres of gulley head per degraded hectare

= 400 slips/ha

Figure A.0.1: Calculations for the required number of grass slips per metre of gulley for agrogassing purposes.

Table A.0.5: Intervention D: Grazing management.

Grazing management				
Item	**Unit cost**	**Quantity**	**Cost**	**Comments**
Uniforms	1,400.00	50	70,000.00	Two uniforms are bought per LCA each year (hence 25*2 = 50)
Wages	30,000	12	360,000.00	2x Eco-rangers per village at R3,000/month = R3,000*10 = R30,000/month for 12 months
Auction	50,000	1	50,000.00	
Vets	38,000.00	1	38,000.00	
Total			**518,000.00**	

------------------------ END OF APPENDIX A ------------------------

Appendix B - Manuscript

land

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Article

Drivers of Degradation of Croplands and Abandoned Lands: A Case Study of Macubeni Communal Land in the Eastern Cape, South Africa

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Abstract: Soil erosion is a global environmental problem and a pervasive form of land degradation that threatens land productivity and food and water security. Some of the biggest sources of sediment in catchments are cultivated and abandoned lands. However, the abandonment of cultivated fields is not well-researched. Our study assesses the level of degradation in cultivated and abandoned lands using a case study in South Africa. We answer three main questions: (1) What is the extent of crop field degradation on used, partly used, and abandoned fields? (2) What are the drivers of field abandonment in relation to land degradation? (3) Can proposed sustainable land management interventions tackle the dynamics of land abandonment and associated degradation? To answer these questions, cultivated and abandoned lands were mapped in a pilot catchment with ArcGIS tools and assigned severity codes and classified according to status, degradation, and encroachment. Systems diagrams were developed to show the interactions between agricultural land use and the level of degradation and leverage points in the system, with interventions assessed via a multi-criteria analysis. The results revealed that 37% of the total mapped area of croplands in the pilot site was abandoned and 20% of those lands were highly degraded. We argue that the innovative application of systems thinking through causal loop diagrams (CLDs) and leverage point analysis, combined with spatial and multi-criteria analyses, can assist with planning SLM interventions in similar contexts in the developing world.

Keywords: sustainable land management; system dynamics; leverage points; multi-criteria analysis; rehabilitation; livelihoods

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1. Introduction

Degradation in the form of soil erosion is a major environmental problem globally [1,2]. Although it is a natural process, it is often exacerbated by human activities such as intensive agricultural practices that lack conservation techniques, e.g., inappropriate cultivation and overgrazing [3,4]. Hence, 52% of the world's agricultural land is moderately to severely degraded [1]. The African continent is considered the most vulnerable and severely affected by land degradation, with desertification threatening over 45% of the region [5]. Most degradation in Africa occurs on agricultural lands, with a ruinous effect on food security for a large portion of the population [5].

Most croplands contribute to land degradation in the form of soil erosion that differs in severity according to whether they are currently being used or abandoned [6]. With the exception of a zero tillage technique, the soil is disturbed during cultivation and remains that way for a long time even after all agricultural activities have been halted. Therefore, the sediment yield often increases, and abandoned lands become erosion hotspots, which increases gully formation [6]. Sedimentation from croplands negatively affects water availability and ecosystem health due to high siltation [7].

The number of abandoned fields has been growing throughout southern Africa [8,9]. Hebinck et al. [10] argue that this is due to the overall strengthening of rural–urban connections, while Shackleton and Luckert [11] attribute it to globalisation and modernisation. Some studies suggest that increasingly diversified household incomes and activities [12] and changes to 'agrarian' identities [10] also play a role in increasing the extent of abandoned lands. The range of factors influencing the abandonment of cultivated land illustrates the complexity of the system and thus the utility of systems thinking as a framework for approaching these interconnections.

Although there is a wealth of research on gully systems [4,13,14], little has been done in conjunction with currently or previously cultivated fields. Our study assessed the level of degradation in cultivated and abandoned fields using a case study in South Africa, addressing three main research questions: (1) What is the extent of crop field degradation on used, partly used, and abandoned fields? (2) What are the drivers of field abandonment in relation to land degradation? (3) Can proposed sustainable land management interventions tackle the dynamics of land abandonment and associated degradation?

1.1. Conceptual Framework

In this paper, we apply a systems thinking approach to assess the interconnections and feedbacks [15] between land abandonment, degradation, and sustainable land management. Leverage points are a component of the systems thinking framework to explore the relative strengths and weaknesses of interventions in the system [16]. The methods section later illustrates how qualitative systems modelling [17] was used to describe and analyse the problem and associated interventions, nested inside of a multi-method approach. First, we define land degradation, land abandonment, and leverage points to conceptually frame our study.

1.1.1. Land Degradation

Land degradation is defined as the reduction or loss of land productivity (biological or economic) through habitat patterns or human activities such as soil erosion or long-term loss of natural vegetation [18,19]. Soil erosion is particularly prevalent as a form of land degradation in relation to cultivated lands. The risk of sheet erosion increases on cultivated lands due to the soil structure being disturbed and soil being exposed to the erosive effects of rainfall [3,6]. As water flows across the soil surface, erosional features (such as rills) form [20]. If the erosion persists, the rills develop into gullies [21]. Multiple studies have found that abandoned cultivated lands are both causes and symptoms of land degradation: as gullies form on abandoned fields, the fields become more likely to be permanently abandoned and act as major sources of sediment, increasing the sediment load in the catchment's water bodies with negative effects on water availability and water quality [22,23]. Land degradation in many parts of the developing world has been associated with a range of factors, including unsustainable agricultural practices, inappropriate fire management, bush encroachment, drought, overgrazing, and ineffective land use planning [24,25].

1.1.2. Land Abandonment

As highlighted by Blair et al. [26], the natural and socio–economic aspects of agricultural activities are interconnected at various scales, which often creates difficulties in defining abandoned lands. For instance, farmlands temporarily cleared or left fallow for short periods due to factors such as drought or a temporary lack of labour may be mischaracterised as abandoned lands [10]. In this study, the term abandoned fields, as defined by Blair et al. [26], refers to a parcel of land on which all crop agricultural activities have ceased. There are various implications of these abandoned fields. From an ecological perspective, they broadly include the alteration of ecosystem services, habitats, biodiversity, hydrological regimes, carbon sequestration, and soil fertility [27]. Moreover, there is a wide range of reasons across countries around the world for the existence of abandoned fields. These include factors such as lack of draught power, rainfall variability and droughts, and perspective, they broadly include the alteration of ecosystem services, habitats, biodiversity, hydrological regimes, carbon sequestration, and soil fertility [27]. Moreover, there is a wide range of reasons across countries around the world for the existence of abandoned fields. These include factors such as lack of draught power, rainfall variability and droughts, and cultural and socio–economic shifts such as increasingly modernised youth shifting away from the agrarian lifestyle [26]. Unsustainable and inappropriate agricultural practices also play a role in land abandonment in many countries. In South Africa, unsustainable agricultural practices include inappropriate irrigation, which can raise the water table level and, following evaporation and evapotranspiration, result in soil salinisation, reducing the land productivity [28]; and inappropriate cultivation, which disturbs the soil structure, increasing the vulnerability of crop fields to erosion [6]. Poor (or non-existent) grazing management can also result in livestock destroying in-use crop fields and grazing on abandoned lands, resulting in soil compaction and sheet erosion [29]. The range of factors influencing the abandonment of cultivated land further highlights the complexity of the system and thus the need to use a systems thinking approach.

1.1.3. Leverage Points and Interventions

Meadows [16] defined leverage points as places in a complex system where a small change made in a specific part results in a big change in the whole system. Meadows [16] listed 12 places to intervene in a system. The points of lowest leverage are not the least important. However, they are often short-term oriented and least likely to cause a significant long-term change in the system [16]. In essence, higher points of leverage in a system tend to have more impacts on future outcomes than the present because they are vision-based [30]. It is also emphasised in the literature that knowing the root causes of a problem makes it easier to deal with and possibly reverse said problem [31,32]. Therefore, we focused on system drivers of field abandonment, the way in which field abandonment influences degradation more broadly, and whether interventions are capable of tackling the root causes of field abandonment (as per research question 3).

Meadows' list of leverage points has been adapted over the years by different studies. Drawing from Meadows' list, Abson et al. [33] argue that sustainability interventions frequently target places in the system that hold low leverage and thus have very limited potential for transformational change. By conceptualizing and analyzing the dynamic interrelationships between system variables and systems thinking, modelling supports the identification of high leverage points in the system that seek to avoid siloes [33]. In this study, we draw from Abson et al. [33] and Meadows' [16] systems framework for leverage points for sustainability (as summarised in Figure 1).

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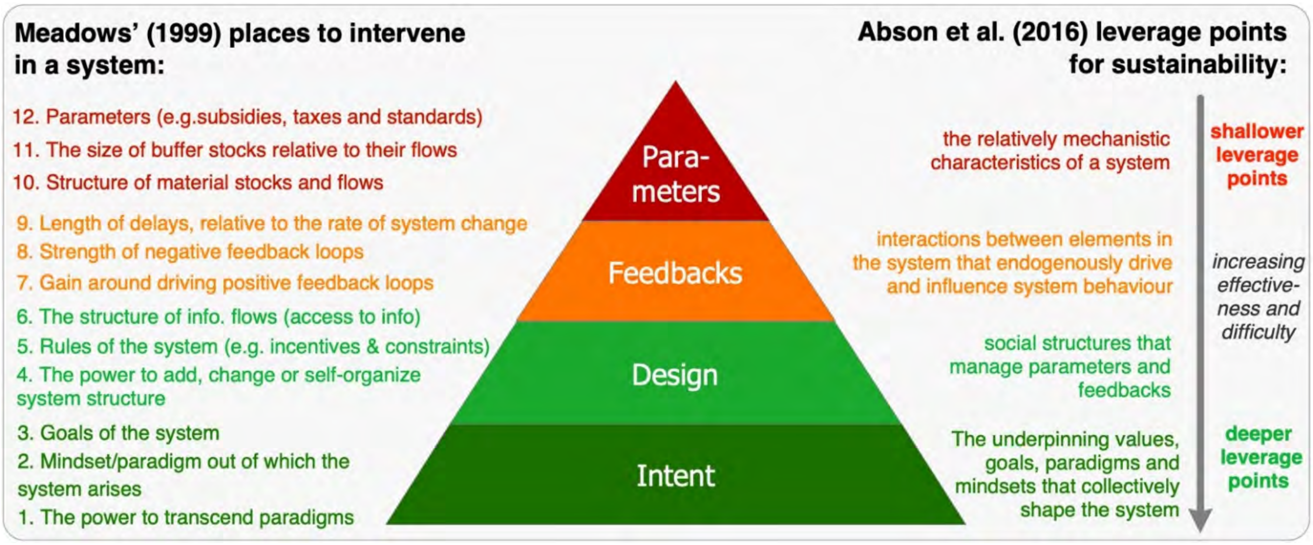

Figure 1. Visual summary of Meadows' twelve leverage points (left) and Abson et al.'s [33] reframing of the leverage points as four categories of system characteristics (right). Adapted from Abson et al. [33] and Meadows [16].

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2. Materials and Methods

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2.1. The Study Area

2.1. The Study Area

Macubeni catchment, South Africa, is used as a case study for assessing the level of degradation in croplands and the drivers of land abandonment in relation to degradation. The Macubeni communal land (31°30′53.92″ S; 27°9′53.49″ E) is located within the Emalahleni Local Municipality in the Eastern Cape Province, covering 16,150 ha of land in the upper reaches of the Cacadu River catchment (Figure 2) [34].

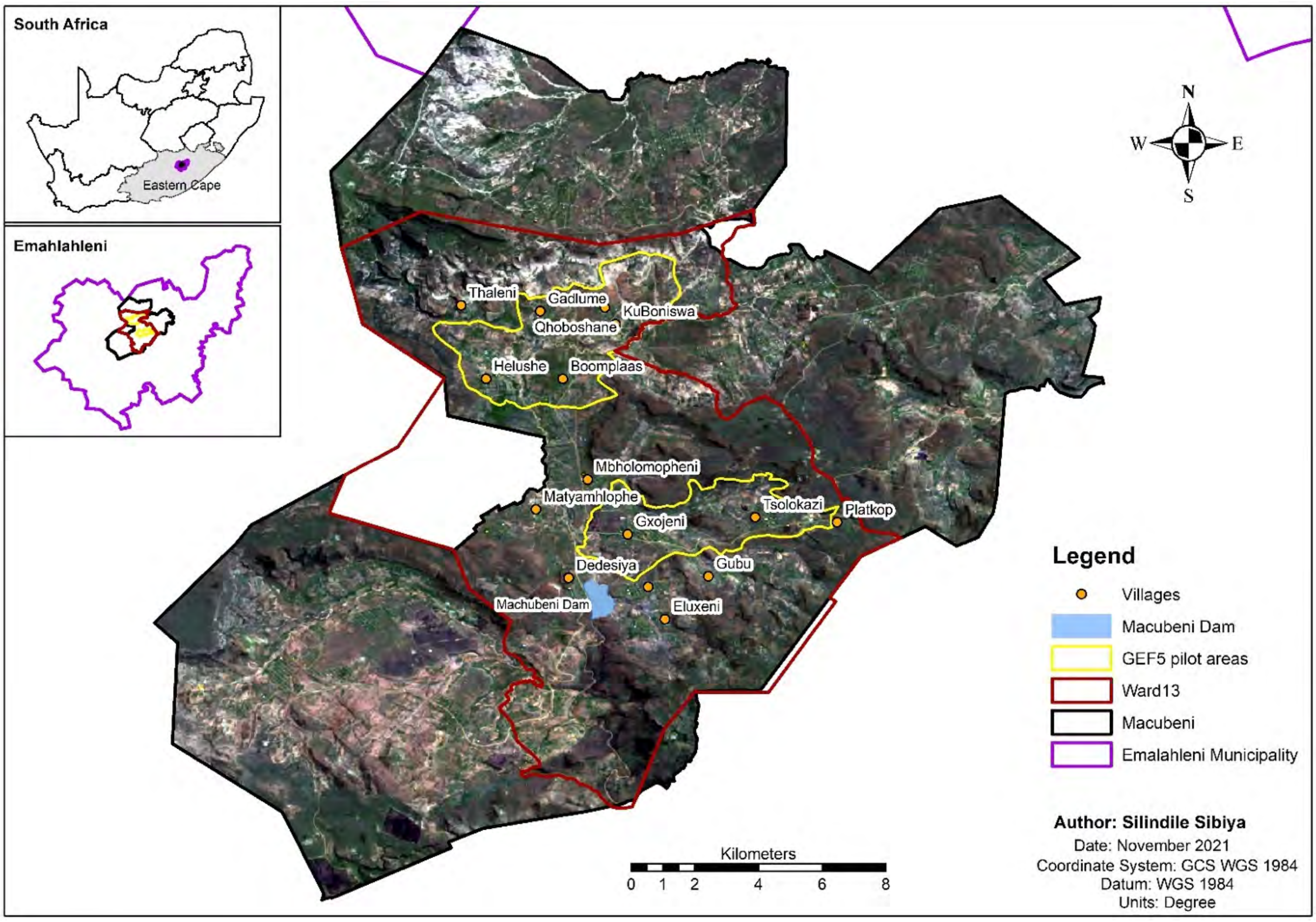

Figure 2. Map showing the location of Macubeni area as the study site of the Global Environmental Facility 5th funding cycle (GEF5) Sustainable Land Management project.

The altitude of the hilly and mountainous terrain of Macubeni ranges between 1300 and 2100 m above sea level. Macubeni generally possesses stony and shallow soils [34], which makes it susceptible to erosion.

As a result, it falls within what is considered the most degraded communal lands in the Eastern Cape, and possibly in South Africa as a whole [24]. Gully erosion has been documented to be a major challenge in the Eastern Cape, with the soil erosion rate exceeding 12 t/ha/yr [35] and the eroded soil being deposited into rivers in the catchment, which drives the sedimentation of dams and reduces water availability for downstream stakeholders [24]. This is of particular concern in Macubeni because the Macubeni Dam, which is downstream of many agricultural fields, is the primary water supply source for the town of Cacadu (previously called 'Lady Frere') and the surrounding villages. Cacadu is the seat of the Emalahleni Local Municipality and the fact that the Macubeni Dam is silting up, with implications for the dam's capacity and for the water quality, has been a longstanding issue and a primary motivator for SLM interventions in the region [36].

The relationship between cultivated lands, degradation, and sedimentation in the Eastern Cape is informed by multiple other studies in the region [5,29,37,38]. Livestock grazing and crop-based agriculture are the most extensive land uses, creating the conditions for further soil erosion [34]. Thus, the abundant visible erosion on the hillslopes in Macubeni, in the form of sheet, rill, and gully erosion, is mostly attributed to the combination of erodible soils and poor land management practices, such as overgrazing [39] and inappropriate cultivation [6].

The Tsomo Grassland type and Southern Drakensberg Highland Grassland is Macubeni's natural dominant vegetation type [40]. These have high basal cover and are generally dense grasslands with low grazing potential. The area has an average of 600 mm of rainfall per year and temperatures ranging around 27 °C in summer and 11 °C in winter [41]. More than 70% of the rainfall in the catchment occurs during the summer season, while only 30% of it occurs in winter [36]. Summer rains are often in the form of heavy thunderstorms, reaching up to 50 mm/hour, which have a high soil erosive effect [36].

There are 17 villages within the communal area and 1700 households, with a total population of 7800 people [42]. This study focused on Ward 13 of the Macubeni area and used five villages that a development project, funded by the Global Environment Facility 5th funding cycle (GEF5), worked with between 2015 and 2022, namely: Boomplaas, Helushe, Qhoboshane, Gxojeni, and Platkop. The GEF5 Sustainable Land Management (SLM) Project, out of which this study emerged, aimed to enable the adoption of SLM practices and ecosystem rehabilitation in support of the green economy and resilient livelihoods. The GEF5 project's activities were broadly structured into five hubs: (i) Land rehabilitation hub; (ii) Livestock and Rangeland management hub; (iii) Conservation agriculture hub; (iv) livelihoods hub, and (v) natural resource governance hub (drawing from and building upon suggestions made by Macubeni community members for improved land management and possible solutions to land degradation [43]). For this paper, we have excluded explicitly referring to the livelihoods and governance hubs because they are functionally nested within the other three hubs. The co-authors worked in this GEF5 SLM project and are therefore intimately acquainted with the drivers of degradation in the Macubeni catchment and have drawn from this first-hand experience in conducting this study.

2.2. Overview of the Multi-Method Approach

The problem of abandoned fields as a driver of land degradation was investigated using a multi-method approach of three interconnected processes (Figure 3), undertaken using a single case study approach. The first step in the research process was a spatial analysis that mapped and classified the agricultural lands in the study site and ascribed levels of degradation to them, shown as Step 1 in Figure 3 and detailed methodologically in Section 2.3 below. The second step was qualitative systems modelling in the form of systems diagramming, which conceptualised the drivers of cropland abandonment and, in turn, the way in which abandoned fields are a driver of degradation (Step 2 in Figure 3 and detailed in Section 2.4). The third step was a Multi-Criteria Analysis (MCA) of the interventions undertaken in the study site in relation to abandoned fields (Step 3 in Figure 3, detailed in Section 2.5), which led to a review of the systems diagrams (Step 4) in an iterative loop. These three processes were synthesised using a leverage points analysis (Step 5), which drew from the results of the Spatial analysis, the MCA, and the qualitative system dynamics modelling (as described in Section 2.6). The leverage points analysis was used to refine the systems diagrams (Step 6), leading to the final discussion and recommendations emanating from this study (Step 7).

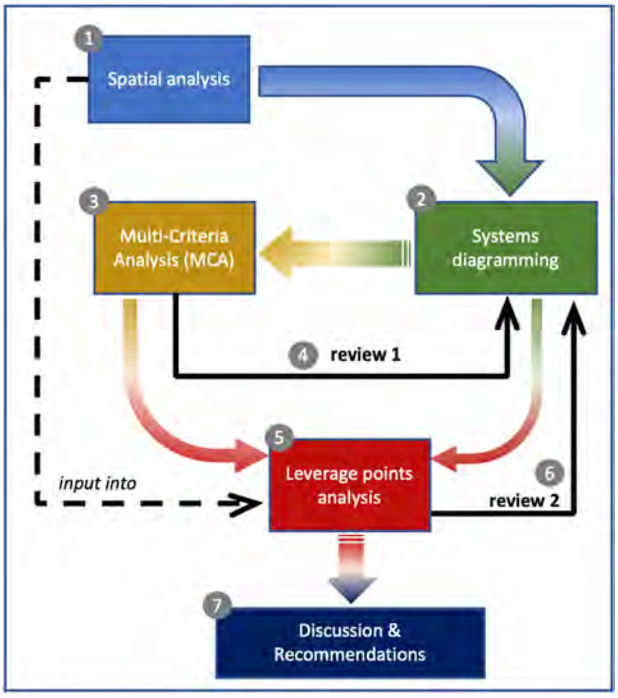

Figure 3. Summary of the research process. The rectangles represent the main steps, with the numbered circles showing the overall sequence. The thick coloured arrows between the research steps denote the primary process flow, with the solid black arrows denoting the main iterations in the form of 'reviews'. Finally, the dashed arrow shows one-way input from the spatial analysis into the leverage points analysis.

2.3. Mapping and Assessing Crop Fields in Macubeni

A digitising tool on ArcMap 10.6 was used to map the crop fields and categorise them according to their use status and degradation. This method was adapted from Schlegel et al. [37], which was developed for the Tsitsa River Catchment, which is another Eastern Cape site with similar biophysical and socio-economic characteristics to the Macubeni catchment. The images of Ward 13 that were used for digitising croplands were sourced from the National Geo-Spatial Information, Pretoria. They are captured at a scale of 1:10,000 with 0.5 m resolution. A total of 840 crop fields were mapped. All the mapped cultivated fields in the study area were classified according to the usage status as the first step in determining the state that each crop field was in. Status refers to the usage of the cultivated land where: Used = currently cultivated; Partly used = part of the field is under cultivation; Abandoned = no longer being cultivated or has not been cultivated for several years. Degradation levels were assessed via the current condition of the cultivated land in terms of visible erosional features, such as rills, gullies, and lack of vegetation cover, where: Low degradation = little or no sheet erosion, with no gullies; Moderate degradation = rills/small gullies/lack of vegetation, and/or sheet erosion; High degradation = abundant erosion/large gullies/visibly abandoned fields. Each degradation class was additionally subdivided into three vulnerability codes. These refer to the probability of the future degradation of the land through erosion or degradation in the absence of any mitigation measures. Further methodological detail on the spatial mapping is provided in the Supplementary Materials.

2.4. System Dynamics Modelling

The potential drivers of degradation and field abandonment were drawn from Macubeni as a case study with stakeholder engagement as part of the GEF-5 SLM project and the literature with case studies of similar catchment characteristics to those of Macubeni. These characteristics include a common nationality (i.e., all case studies are South African) and a common factor of being rural landscapes. Other similarities that were considered for case study comparison were biophysical similarity (including elevation, vegetation, and soil types) and socio–economic similarity (including the socio–economic context and the combination of existing land tenure arrangements and types of land uses).

Drivers of cropland abandonment in South Africa are part of a complex system that includes socio–cultural, bio–physical, and economic factors [29]. System Dynamics Modelling enables a holistic view of the problem in order to better represent, analyse, and understand it [29]. To this end, Vensim © v.9.1 2019 (Ventana Systems) was used to develop causal loop diagrams (CLDs) to describe and present the interconnections between different drivers in the system, along with the balancing and reinforcing feedback loops driving system behaviour [15]. The resulting qualitative systems model was used to explore and visualise the interactions among agricultural land use, the level of degradation, and SLM interventions that are aimed at reducing degradation and building green livelihoods.

2.5. Multi-Criteria Analysis

Multi-Criteria Analysis (MCA) is a broad category used to describe formal and structured approaches for individuals and groups to determine overall preferences among alternative options, accounting for economic, environmental, social, and technological aspects of problems [44]. As a class of approach, MCA can bring a degree of structure, transparency, and flexibility that lie beyond the practical reach of Cost–Benefit Analysis (CBA) [45]. In this study, a simple form of MCA was applied as part of the multi-method approach, complementing the spatial analysis and the systems diagramming methods. The input was solicited during a stakeholder virtual workshop, hosted in December 2021, with seven of the GEF5 SLM project team leaders, including representatives of each of the five project hubs introduced earlier.

Drawing from the approaches outlined by CLG [45] and Mellville-Shreeve et al. [46], the following steps were employed: (1) the problem definition and the decision context were defined by drawing on the initial results of the analyses from the preceding steps (see Figure 3); (2) the options to be compared against one another were then defined as the interventions in the case study site; (3) the objectives and criteria were subsequently defined [45]; (4) the performance matrix was populated with the MCA results, which were calculated from a combination of cost data and stakeholder input and then converted into consistent numerical values (i.e., normalised); and finally, (5) the performance of the interventions were evaluated against the criteria.

Table 1 shows a generic performance matrix, as used in the MCA step (4). In this example, three interventions (A,B,C) were assessed against two criteria (1,2). The criteria were weighted according to perceived relative importance (Criterion 1 was weighted at 30% and Criterion 2 was 70%). The direction of each criterion corresponds with whether higher values of a criterion are desirable (+1) or undesirable (−1). In the case of costs, for example, the lower the cost the better, and so a higher cost is undesirable (hence, the direction is −1). Each intervention was then scored, with the performance multiplied against the weighting and the direction (e.g., for Criterion 1, Intervention A's score was 2, with the weighted performance calculated as 2 × 0.3 × −1, for the result of −0.6).

Table 1. Generic performance matrix. Wt = weight; Wt'd perf. = weighted performance.

			Interventions					
			Intervention A		Intervention B		Intervention C	
	Wt	**Direction**	**Perf.**	**Wt'd Perf.**	**Perf.**	**Wt'd Perf.**	**Perf.**	**Wt'd Perf.**
Criterion 1	0.3	−1	2	−0.6	1	−0.3	4	−1.2
Criterion 2	0.7	1	3	2.1	2.5	1.75	3.5	2.45
Score	-	-	-	1.5		1.45		1.25

Further details about the MCA are available in the Supplementary Materials.

2.6. Leverage Points Analysis

The final step of the multi-method process was to synthesise the results of the spatial analysis, the MCA, and the qualitative system dynamics modelling using a leverage points analysis (Step 5 in Figure 3). The leverage points analysis was used to review the systemic conceptualisation to further refine the systems diagrams by capturing additional variables and feedback loops that were surfaced through the preceding steps (this refinement is labelled as 'review 2', Step 6, in Figure 3). The leverage points framework, summarised in Figure 1, was used to structure the discussion of the interventions, the implications of which form the basis of the final discussion and the recommendations emanating from this study (Step 7 of Figure 3).

3. Results

We present our results in four parts. First, the results of the spatial analysis on the use and levels of degradation of crop fields are presented (Section 3.1). Next, the dynamics of land abandonment in relation to degradation are presented in the form of systems diagrams (Section 3.2), followed by the results of the multi-criteria analysis, which assessed the relative strengths and weaknesses of the different interventions aimed at improving sustainable land management in Macubeni (Section 3.3). The results are then synthesised using the leverage points framework, with the existing sustainable land management (SLM) interventions assessed in relation to the dynamics of land abandonment and degradation (Section 3.4).

3.1. Use and Degradation of Crop Fields in Macubeni

A total of 840 crop fields were mapped, covering an area of 3160 hectares (ha) (see Figure 4). Almost half of the number of mapped fields (395 out of 840, or 47%) were partly used (orange-shaded fields in Figure 4); abandoned fields accounted for 30% of the fields (purple-shaded), with the smallest percentage of fields (23%) in use (yellow-shaded).

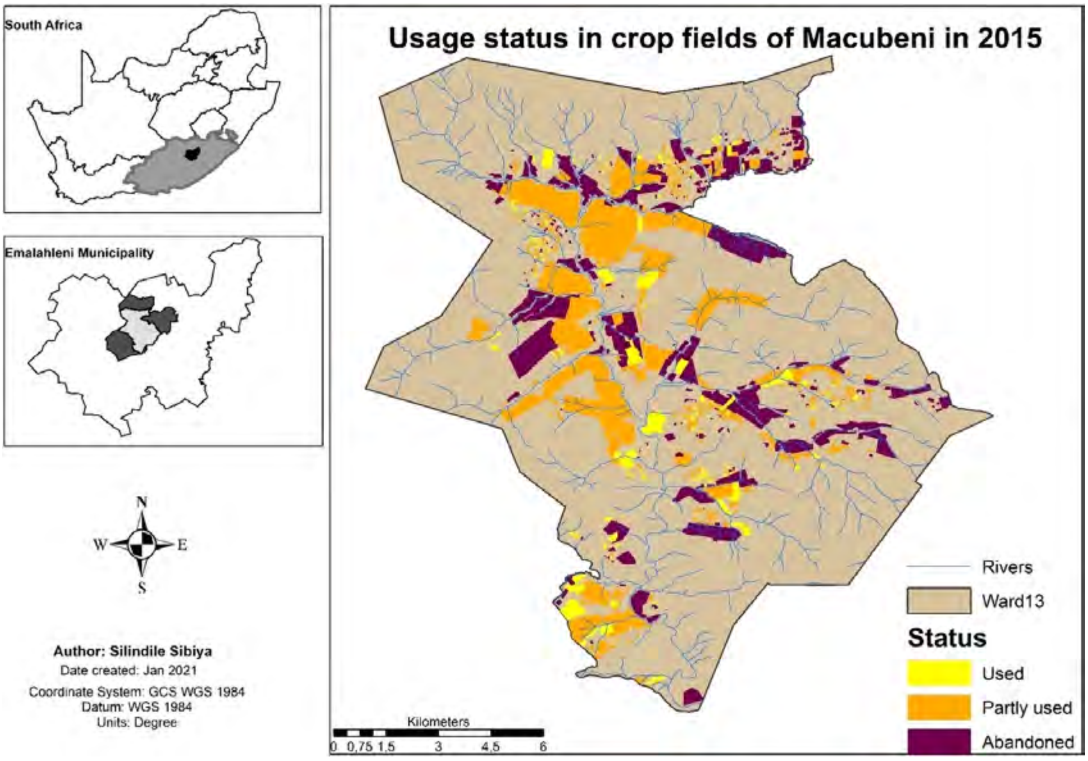

Figure 4. The spatial distribution of used, partly used, and abandoned crop fields in Macubeni.

Figure 4. The spatial distribution of used, partly used, and abandoned crop fields in Macubeni.

As seen in Figure 5A, almost half of the fields were highly degraded, accounting for 47% of the area of all the crop fields. The highly degraded fields were mostly located around drainage lines where the fields are especially susceptible to erosion (and where, in turn, the degraded fields increase sedimentation into the river systems, reducing dam capacity downstream). Fields with moderate degradation constituted 36% of the total area, while those with low degradation covered the smallest area of only 16.5%.

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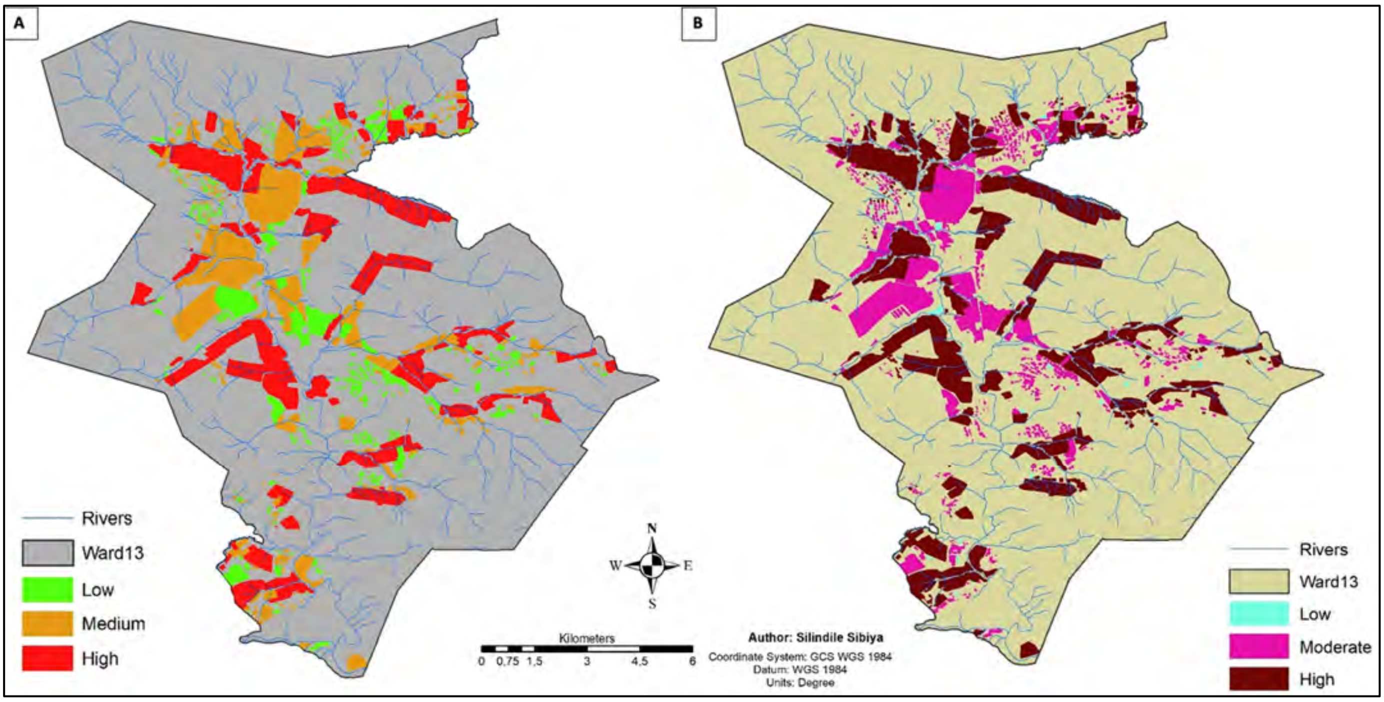

Figure 5. (**A**) Level of degradation in the croplands of Macubeni, Ward 13; (**B**) vulnerability to degradation.

The vulnerability level of crop fields, shown in Figure 5B, speaks to the potential risk that the area will be degraded in the future, judging by the features already exhibited by the crop field itself or degradation-related landscape characteristics in the surrounding area. About 65% of the crop fields were categorised as highly vulnerable to further erosion, with about 34% rated as moderately vulnerable and <1% rated at a low level of vulnerability. Further details, including tables containing the exact results, can be found in Sections S.3–S.6 in the Supplementary Materials.

In summary, the relationships between field abandonment, land productivity, soil conditions, and erosion point to a range of interconnecting factors and dynamics that drive abandonment and suggest a relationship between the way in which abandonment, in turn, drives degradation. This is explored in the following sub-section.

3.2. The Dynamics of Land Abandonment in Relation to Degradation

This section presents the authors' conceptualisation of the drivers of cropland abandonment and the way in which abandoned fields are a driver of degradation, which is jointly referred to here as 'the dynamics of land abandonment'. The conceptualisation is represented with systems diagrams, using the diagrammatic conventions of causal loop diagrams (CLDs (see Table 2). A single CLD is presented, with the feedback loops and variables unfolded in a stepwise fashion over three stages (Figures 6–8).

Table 2. Diagrammatic conventions of Causal Loop Diagrams.

Symbol	Description
→ +	Positive relationship (where a change in the cause results in a change in the effect in the same direction—i.e., an increase in the cause results in an increase in the effect, and vice versa)
→ -	Negative relationship (where a change in the cause results in a change in the effect in the opposite direction—i.e., where an increase in the cause

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-	Negative relationship (where a change in the cause results in a change in the effect in the opposite direction—i.e., where an increase in the cause results in a decrease in the effect, and vice versa)
||	Delayed effect
R1	Reinforcing feedback loop
B1	Balancing feedback loop
stock	Stock variables can be anything that accumulates and de-accumulates (both material, such as water in a dam or total agricultural land, and non-material, such as trust). All feedback loops must include at least one stock.

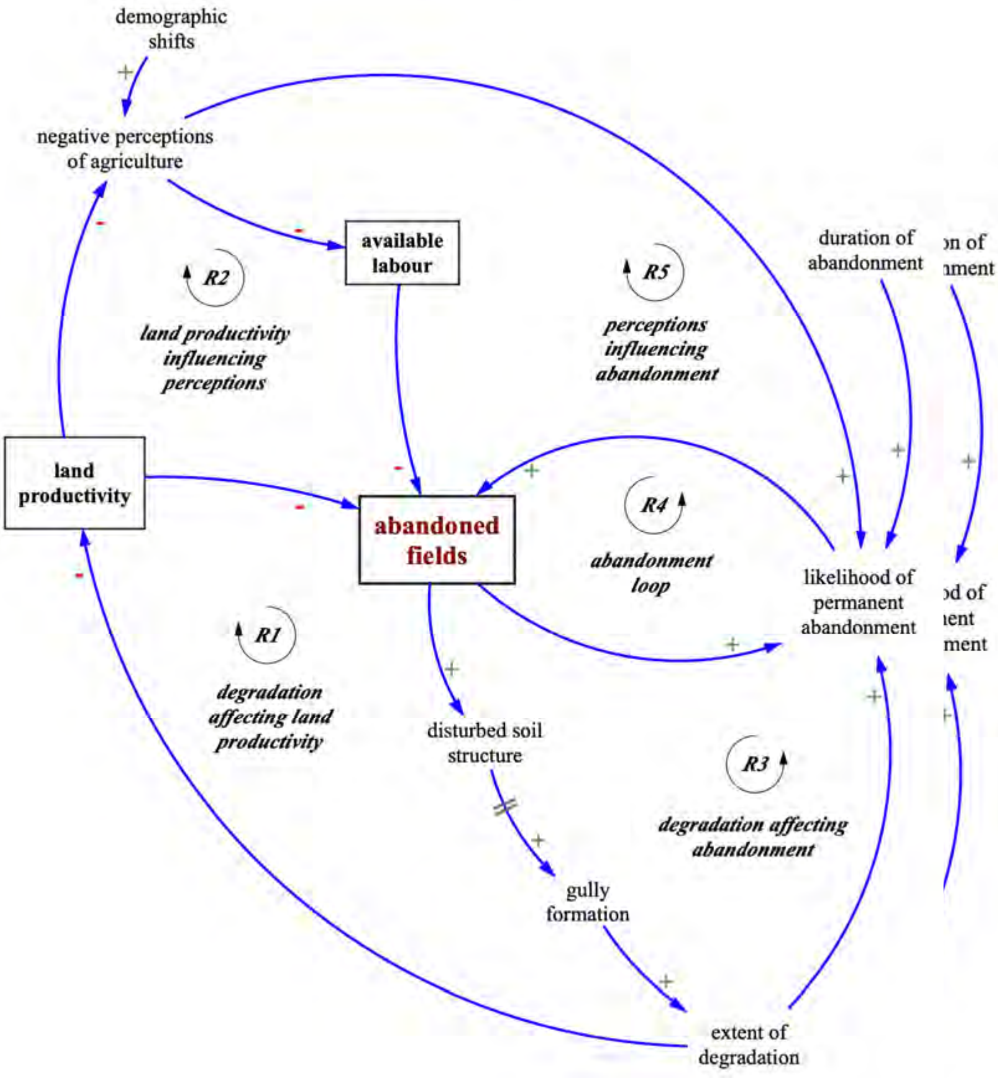

Figure 6. Introductory diagram for drivers of abandoned lands (Version 1 of 3 causal loop diagrams (CLDs)), showing three stock variables (in boxes) and five reinforcing ® feedback loops. See Table 1 for full explanations of the diagrammatic conventions.

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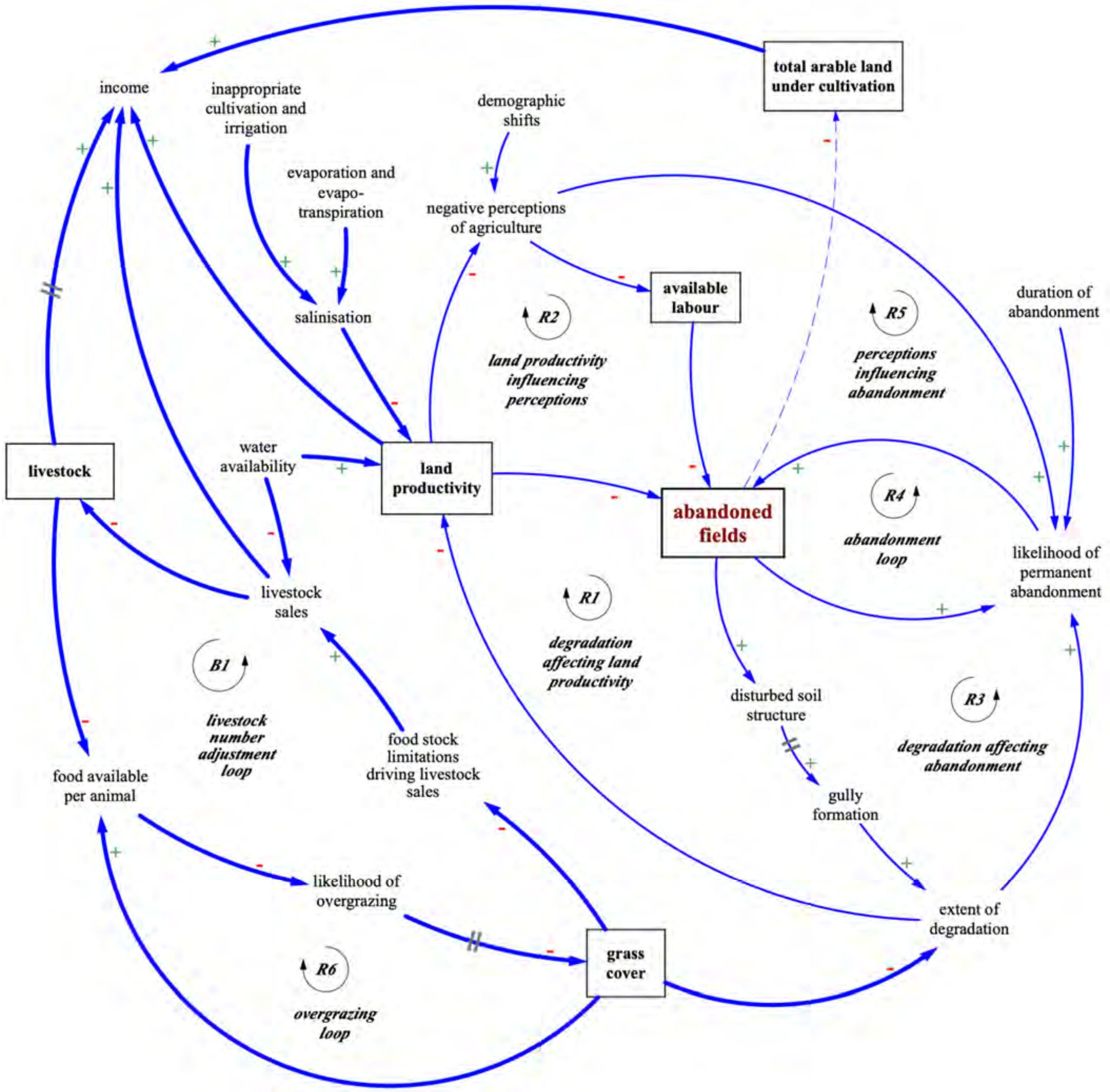

Figure 7. Version 2 of the CLD showing reinforcing loop (R1) for agricultural practices, loop (R2) for land productivity, loop (R3) of labour, and loop (R4) for degradation. Note that the dashed arrow between ‘abandoned fields’ and ‘total arable land under cultivation’ is only for presentation purposes to differentiate overlapping arrows.

The first version of the CLD (Figure 6) introduces the drivers of cropland abandonment via a central stock of abandoned fields, which is impacted by the dynamics of two other stocks, namely land productivity and the available labour (which represents the overall labour pool for working croplands in the region). If abandoned lands increase, there will be more land with disturbed soil structure, which, over time, creates the conditions for gullies to form, increasing the overall extent of degradation (note that the double-lined mark on the arrow between ‘disturbed soil structure’ and ‘gully formation’ signifies a delay between cause and effect). This negatively impacts land productivity [42–44], further increasing the number of abandoned fields, closing the first reinforcing feedback loop (R1) (degradation affecting land productivity). With land productivity decreasing, many people's perceptions of agriculture become more pessimistic, given that they see agriculture as being unable to generate income and sustain livelihoods [9,47]. This reduces the available labour pool, further driving field abandonment and forming the second reinforcing feedback loop (R2) (land productivity influencing perceptions).

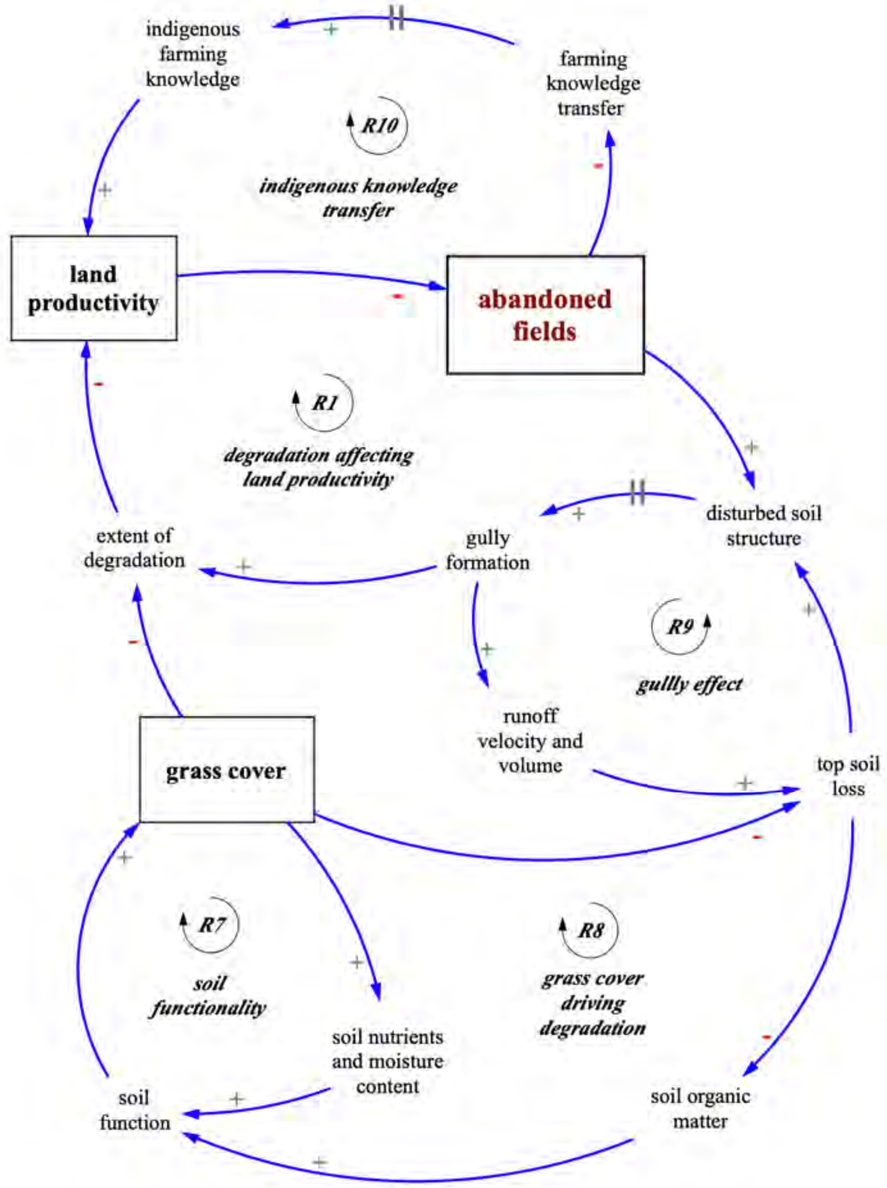

Figure 8. Expanded CLD (version 3).

Figure 8. Expanded CLD (version 3).

Negative perceptions of agriculture are also being driven by demographic shifts in the area. As with many rural parts of South Africa, most fields are owned by the older generation and lack a willing and able youth population to take over the farming of the fields [47]. The proportion of younger people in the villages is increasing, with migration to cities increasing as people leave rural areas in search of urban employment opportunities [9]. Another important variable determining the quantity of abandoned lands is whether people are inclined to reclaim the abandoned lands and start farming them again or whether people are more inclined to permanently abandon the fields. This is captured in Figure 6 with the variable 'likelihood of permanent abandonment', which is impacted by four factors. First, if the extent of degradation is high, then the likelihood of permanent abandonment will be high, which, in turn, further increases abandoned

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fields via two reinforcing feedback effects (R3) (degradation affecting abandonment) and R4 (abandonment loop). The abandonment loop (R4) captures the vicious cycle that can develop whereby people see their neighbours and friends permanently abandoning their fields, and this discouraging pattern serves to increase the likelihood of individuals and families permanently abandoning their own fields. Third, the likelihood of permanent abandonment increases along with the increasing negative perceptions of agriculture (R5) (perceptions influencing abandonment). Finally, the likelihood of permanent abandonment increases with the duration of abandonment, following the logic that the longer the current field has been abandoned, the greater the existing level of degradation, and therefore the more likely this field is to be permanently abandoned.

Version 2 of the CLD (Figure 7) expands on the initial drivers of abandoned lands to include three new stock variables, two additional feedback loops, and two water-related drivers (the connections between these new variables are shown via the emboldened arrows in Figure 7). A high-level system indicator is included in the form of income, which is primarily derived from livestock sales, the total arable land under cultivation, and from land productivity (all of which are positively related so that if livestock sales, land productivity, and the total arable land under cultivation all increase, then the total income will increase). Livestock sales affect income in both direct and indirect ways. An increase in livestock sales will directly increase income in the short-term, but it will decrease the stock of livestock. Given that livestock is a form of capital held by catchment residents as an asset class, selling livestock means foregoing the income derived from the sale of livestock products (such as milk) as well as reducing the capital stock held by catchment residents, which, over time, can be converted into income through future livestock sales. The delay mark on the arrow between livestock and income shows that the relationship between livestock and income is delayed by the time it takes to convert livestock into income.

The total arable land under cultivation is reduced by the extent of abandoned fields. The more the abandoned fields, the less the total arable land under cultivation and the less the possible income from agriculture. The positive relationship between land productivity and income counters the increase (or decrease) in total arable land under cultivation: if land productivity is high but the total arable land is low, then the productivity of existing arable land can offset the lower quantity of land under cultivation. Conversely, if the total arable land is high but land productivity is low, then the income earned from agriculture will reduce.

Land productivity is impacted by water-related variables in two main ways. Firstly, inappropriate cultivation and irrigation promote poor drainage, which leads to more infiltration and an increased water table level [48]. The raised water table increases the concentration of salt content in the soil as evaporation and evapotranspiration takes place, resulting in salinisation, which reduces land productivity [28].The variable water availability recognises that, in the case of rainfed crops, land productivity is heavily reliant on rainfall [49]. Water availability also captures the reliance of livestock owners on rainfall for livestock watering and for maintaining natural forage in the grazing areas. In times of drought, when water availability reduces, livestock farmers will often increase livestock sales in order to reduce their water and forage requirements, which increases income at the expense of reducing the stock of livestock (which is one of the most important forms of household capital in the area [50]. The adjusting of livestock numbers in relation to food availability is shown by the balancing loop 1 (B1). If the number of livestock increases, the food available per animal decreases, which increases the likelihood of overgrazing occurring, which in turn reduces the overall stock of grass cover in the region [4]. As with water availability in relation to livestock watering, food stock limitations can drive livestock sales, which reduces the overall livestock numbers and increases the food available per animal in an overall balancing loop (B1). Overgrazing also has a reinforcing effect, where a reduction in the food available per animal (due to a growth in livestock population) increases the likelihood of overgrazing, which decreases the grass cover, which further decreases the food available per animal (R6) (overgrazing loop).

Version 3 of the CLD (Figure 8) further expands on the drivers of abandoned lands. Decreasing grass cover reduces soil nutrients and moisture content. One way in which this driver manifests in Macubeni and similar ecosystems is through decreasing grass cover resulting in an increase in invasive and expansive woody species, which have a higher nutrient uptake from the soil, with an associated net decline in soil function, which has a negative knock-on effect on grass cover. This relationship between grass cover and soil functionality is captured in the seventh reinforcing feedback loop (R7).

Soil functionality is also impacted by soil organic matter, which is reduced by topsoil loss. An increase in gullies increases the overall velocity and volume of rainfall runoff on the landscape (as rainfall flows through the channels formed by the gullies), which drives topsoil loss and, via decreasing soil organic matter and an associated reduction in soil function, this further reduces grass cover. This feeds into overall degradation, impacting land productivity and abandoned fields and forming the eighth feedback loop (R8) (grass cover driving degradation). Topsoil loss also drives disturbed soil structure, which increases gullies, driving runoff velocity and volume, creating further topsoil loss. This forms the ninth feedback loop (R9) (gully effect). As noted in Section 2.1, heavy summer thunderstorms are a feature of the rainfall patterns in Macubeni. These thunderstorms are typically of short duration, with high intensity and large raindrops, constituting erosive rainfall events that drive topsoil loss and contribute to land degradation [49,51], interacting with feedbacks R7 (soil functionality), R8 (grass cover driving degradation), and R9 (gully effect).

As more farmers abandon their crop fields, the transfer of indigenous knowledge from the older to the younger generation declines [48]. Over time, decreasing farmer knowledge transfer perpetuates the loss of indigenous knowledge from the older generation and reduces land productivity, with an associated increase in field abandonment, forming R10 (indigenous knowledge transfer).

Having structured the drivers of land abandonment in the form of a CLD, unfolded in three steps between Figures 6 and 8, we now assess the interventions that are aimed at improving sustainable land management in Macubeni.

3.3. Assessing Interventions Using a Multi-Criteria Analysis (MCA)

As noted in the introduction, the GEF5 SLM Project's activities in the Macubeni catchment are grouped into three main hubs: (i) the Land Rehabilitation hub; (ii) the Livestock and Rangeland Management hub; and (iii) the Conservation Agriculture hub. Table 3 summarises the interventions in Macubeni that have a direct or indirect impact on abandoned fields, relating each intervention to its associated 'hub' within the GEF5 SLM Project.

Table 3. Summary of the interventions.

Intervention	Description	Associated GEF5 SLM Programme
A. Sediment trapping structures	Reducing sediment yield from rill and gully erosion, using stone lines, brush silt traps, and stone packs	Land Rehabilitation Hub
B. Climate Smart Agriculture	Improving agricultural adaptation to climate change, including improving tillage practices, increasing soil cover via mulching, and crop rotation to increase plant diversity	Conservation Agriculture Hub
C. Agrograssing	Revegetating bare patches of land, focusing on gully heads	Land Rehabilitation Hub
D. Grazing management	Shifting from open-access grazing regimes, to using camps and rotational grazing	Livestock and Rangeland Management Hub

The results of the MCA are detailed here in Tables 4–6 (with supporting information in the Supplementary Materials). The criteria used in the MCA were the following: Criterion 1—cost—which drew from relevant financial data; Criterion 2—reliance on external funding—which acted as a proxy for the relative robustness of each intervention; and Criterion 3—efficacy—which provided a measure of stakeholders' perceptions of the impact of an intervention.

Table 4. Summary cost data for Criteria 1 (C.1) of the Multi-Criteria Analysis. All costs are represented in South African Rand (ZAR), calculated on an annual basis. Costs are normalized against the highest cost intervention (C. Agrograssing). Cross-references to Tables S2–S5 refer to the supporting information in Supplementary Materials.

Intervention	Total Cost (ZAR)	Normalised Cost	Supporting Information
A. Sediment trapping structures	526,500	0.30	See Table S2
B. Climate Smart Agriculture	305,500	0.17	See Table S3
C. Agrograssing	1,782,240	1.00	See Table S4 and Figure S1
D. Grazing management	518,000	0.29	See Table S5

Table 5. Stakeholder (SH) workshop ratings for criteria 2 (C.2) and 3 (C.3) of the MCA. Avg. = average score; Max. = maximum score.

		Stakeholder (SH)							Scores		
Criteria	Intervention Options	SH #1	SH #2	SH #3	SH #4	SH #5	SH #6	SH #7	Avg.	Max.	Norm-alised
Reliance on external funding (5 = no reliance; 1 = completely reliant)	A. Sed. Trapping structures	1	1	2	3	3	3	1	2.0	5	0.40
	B. Climate Smart Agriculture	2	3	3	3	2	2	3	2.6	5	0.52
	C. Agrograssing	2	2	2	2	3	2	2	2.1	5	0.42
	D. Grazing management	2	2	2	4	1	1	2	2.0	5	0.40
Perceived efficacy (10 = very effective; 0 = completely ineffective)	A. Sed. Trapping structures	5	5	5	5	2.5	5	5	4.6	10	0.46
	B. Climate Smart Agriculture	5	5	5	7.5	5	7.5	5	5.7	10	0.57
	C. Agrograssing	5	5	5	5	5	7.5	5	5.4	10	0.54
	D. Grazing management	5	7.5	5	7.5	5	7.5	7.5	6.4	10	0.64

Table 6. MCA Performance Matrix. Perf. = performance; Wt'd perf = weighted performance.

			Interventions							
Performance Matrix			A. Sed. Trapping Structures		B. Climate Smart Agric.		C. Agrograssing		D. Grazing Management	
	Wt	Direction	Perf.	Wt'd Perf.	Perf.	Wt'd Perf.	Perf.	Wt'd Perf.	Perf.	Wt'd Perf.
C1. Cost	0.4	−1	0.3	−0.120	0.17	−0.068	1	−0.400	0.29	−0.116
C2. Funding reliance	0.2	1	0.4	0.080	0.52	0.104	0.42	0.084	0.4	0.080
C3. Efficacy	0.4	1	0.46	0.184	0.57	0.228	0.54	0.216	0.64	0.256
Total	1			0.144		0.264		−0.100		0.220

The interventions' scores in relation to their relative cost are summarised in Table 4, where the most cost-effective intervention was B. Climate Smart Agriculture at ZAR 305,500, and the most expensive intervention was D. Agrograssing at ZAR 1,782,240.

The results of the interventions' scores in relation to the next two criteria are summarised in Table 5. GEF5 project managers were asked to rate each of the intervention options in relation to criteria 2 and 3. In terms of criterion 2, the stakeholders rated Intervention B (Climate Smart Agriculture) as being the least reliant upon external funding, with the average score of each of the seven respondents being 2.6, with a normalised score of 0.52. The other three interventions all scored similarly against this criterion, with both Intervention A (sediment trapping structures) and Intervention D (grazing management) having normalised scores of 0.40 and Intervention C (agrograssing) having a slightly higher normalised score of 0.42. In terms of criterion 3, the stakeholders rated Intervention D (Grazing management) as having the greatest perceived efficacy, with a normalised score of 0.64. Intervention A (Sediment trapping structures) ranked last, with the lowest normalised score of 0.46.

The normalised scores for each of the interventions, in relation to each of the criteria, were then used as inputs into the MCA Performance Matrix (Table 6). As noted with reference to the generic performance matrix (Table 1), each criterion was weighted according to perceived relative importance. Criteria 1 (cost) and 3 (efficacy) were weighted equally to account for 40% of the total score each. Criterion 2 (funding reliance) was weighted at half of the other two criteria (i.e., 20% of the total score)—see the Supplementary Materials for further details. Given that costs should be preferably lower rather than higher, the direction of the cost criterion is −1, so that the higher the costs, the worse the normalised score. The normalised score is included in Table 6 as the performance (Perf.) of each intervention in relation to each criterion. The weighted performance (Wt'd perf.) is then calculated as the product of the score, the weight (Wt), and the direction (hence, for Intervention A. Sediment trapping structures, the normalised score of 0.3 is the performance of Intervention A against Criteria 1 (cost), with the weighted performance of −0.12 being the product of 0.3, 0.4, and −1). The total scores are the sum of weighted performances.

3.4. Leverage Points Synthesis Analysis

The spatial analysis has highlighted the extent of degradation across the Macubeni crop fields and the requirement for SLM interventions. Given the extent of degradation and the pervasiveness of abandoned fields, along with the interconnectedness of the drivers of abandonment (as shown in the systems diagrams), SLM interventions should aim to reduce the drivers of degradation and field abandonment in a way that maximises desirable outcomes, with long-term sustainability in mind, whilst using as few resources as possible. This is where Meadows' [16] leverage points framework is applicable (as introduced in Section 1.1.3 and Figure 1). The four interventions introduced in the preceding section align with particular leverage points. The interventions are shown in Table 7 in relation to their associated leverage points and to their relative MCA ranking.

Table 7. Summary of the interventions' performance on the MCA in relation to each intervention's associated leverage point, ranked in order from highest to lowest leverage points.

Intervention	**Ranking on the Multi-Criteria Analysis (MCA)**	**Associated Leverage Point (Abson et al., 2016 [33] and Meadows, 1999 [16])**
D. Grazing management	2	Point 5: Rules of the System (e.g., incentives and constraints)
B. Climate smart agriculture	1	Point 6: The structure of information flows
C. Agrograssing	4	Point 9: The length of delays relative to the rate of system change
A. Sediment trapping structures	3	Point 10: The structure of material stocks and flows and nodes of intersection

Building on Meadows' proposed framework, Abson et al. [33] emphasise that leverage points in a complex system are typically *inter*dependent rather than *in*dependent of each other. Hence, applying an intervention in one part of the system, affecting a particular leverage point, can have knock-on effects elsewhere in the system that undermine or support the efficacy of another intervention. For this reason, a holistic view of the problem context is required alongside a systemic understanding of the interventions in relation to one another [52]. In Figure 9, the four interventions are located in relation to the systemic

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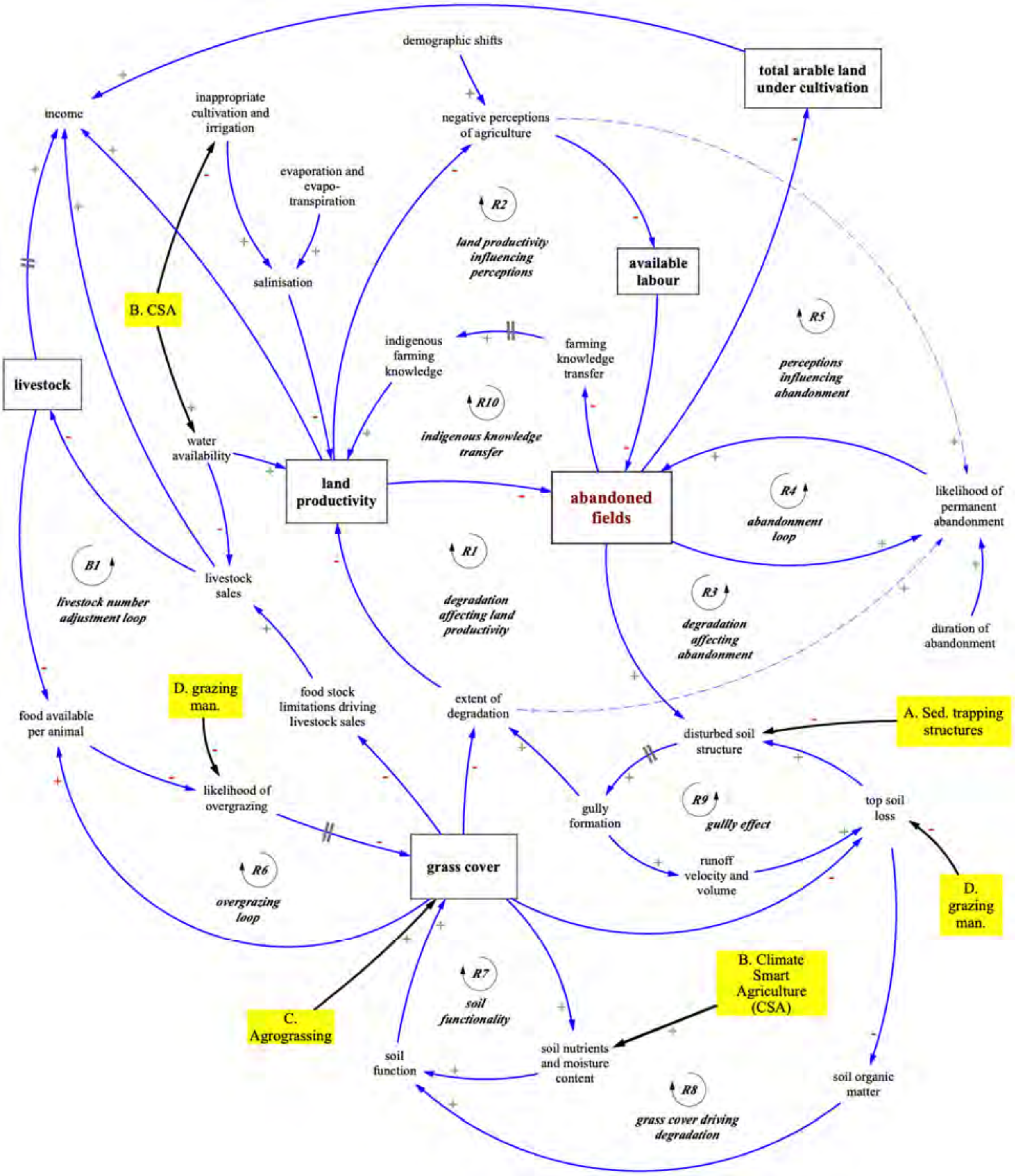

Figure 9. Full causal loop diagram (v.4) indicating intervention points in the system (highlighted in yellow). See Figures 6–8 for a breakdown of the variables and loops shown in an integrated format here. Dashed arrows are for maintaining diagrammatic clarity only in the case of overlapping arrows (and do not, therefore, have a specific meaning). Double-lines on select arrows = delays.

Figure 9. Full causal loop diagram (v.4) indicating intervention points in the system (highlighted in yellow). See Figures 6–8 for a breakdown of the variables and loops shown in an integrated format

Grazing management aims to influence community behaviours via rules and incentives and therefore falls within a deeper leverage point (point 5—the rules of the system). Community members drafted a list of bylaws that everyone needed to agree with and to abide by. This involved the traditional authorities as it included penalties for infringements of the bylaws. The practical activities forming part of this intervention included establishing grazing camps and promoting the rotational resting of camps in the rangelands. These practices enable the community to control the grazing patterns of livestock by only opening certain camps in one season while closing the other for the next season. This intervention impacts the system in several key places. Grazing management reduces the likelihood of overgrazing, which increases grass cover, maintaining and increasing the food available per animal throughout the year, which further reduces the likelihood of overgrazing (loop R6, Figure 9). Increasing grass cover also reduces a primary reason for farmers to sell livestock (namely due to food stock limitations leading to fear of livestock dying or becoming unhealthy). The less reason farmers have to sell, the fewer the livestock sales and the more the livestock. However, maintaining or increasing the number of livestock reduces the food available per animal, which increases the likelihood of overgrazing, driving a decrease in grass cover, which leads to farmers selling livestock in response to food stock limitations. This shows the interaction between the balancing feedback loop B1 and the reinforcing loop R6.

Grazing management also helps reduce topsoil loss both directly and indirectly, via maintaining and increasing grass cover, which reduces soil erosion. Minimizing topsoil loss reduces disturbed soil structure, which reduces the formation of gullies, helping to reduce the impact of rainfall runoff, reducing further topsoil loss (loop R9). An increase in grass cover and a decrease in the formation of gullies both serve to reduce the overall extent of degradation, which positively impacts land productivity (loop R1). Grazing camps constrain the allowable grazing terrain of livestock, which assists with preventing free-roaming livestock from trampling crops. By decreasing the extent of degradation, this intervention could also reduce the likelihood of permanent crop field abandonment.

In principle, the grazing management intervention holds high leverage because the incentives are direct and clear to all the stakeholders and should, therefore, be sustained by the community with little to no external assistance. Yet, the GEF5 project team recognised that, while they had tried to communicate the direct benefits of grazing management to community members, the community members continued to request payment from the project, which explains the low 'external reliance' score for grazing management in the MCA (see Table 5).

Intervention B: Climate smart agriculture (CSA) aligns with leverage point 6, the structure of information flows, which involves restoring or delivering new information into the system that can drive a change in people's behaviors [16]. Introducing improved and more adaptable agricultural practices can shift the reinforcing loop R1 from continuously decreasing land productivity to improving it after some time. Under the GEF5 Conservation Agriculture Hub, 25 agricultural champions were appointed [53] with the idea being that, over time, the visible benefits of increased land productivity in the fields tended by the agricultural champions would persuade other farmers in the region to adopt sustainable agricultural methods. As land productivity increases, the visible benefits of agriculture could also reduce the negative perceptions of agriculture, increasing available labour and decreasing field abandonment (loop R2). Particular CSA practices promoted by the Conservation Agriculture Hub included mulching in order to increase soil cover, which helps to maintain soil nutrients and soil moisture content. This benefits the catchment more broadly as soil functionality improves, which increases grass cover (loop R7), reducing the overall extent of degradation in the catchment and feeding into loop R3. The CSA practice can be implemented with little funding and can deliver more immediate results, meaning that as an intervention it is less reliant on external funding (which is why it scores highest on criteria 2 of the MCA).

Intervention C: Agrograssing aims to improve vegetation cover by planting grass in areas where soil is exposed and erosion rates are high. Considering the difficulties surrounding the successful implementation of this intervention, such as roaming livestock grazing on the grass at an early stage of its growth (if seeds are used) and the slow process of planting and selling Vetiver grass (*Chrysopogon zizanioides*), the length of delays relative to the rate of change in the system through soil erosion are longer. The Livestock and Rangeland Management Hub's activities could support agrograssing via grazing management practices, such as rotational resting, that would help reduce the likelihood of livestock grazing on or trampling upon the grass in early growth stages. A further advantage of Vetiver grass for the purpose of agrograssing in Macubeni is that it is unpalatable to livestock, which reduces the likelihood of livestock grazing on the grass (although grazing management would still be required to prevent trampling) [43]. Improving grass cover can increase soil nutrients, thus positively influencing loop R7. While participating in the MCA, stakeholders noted that if the community were to embrace agrograssing at a larger scale, then the intervention could be more effective, but currently, the scale is too small to be effective for the whole catchment (hence agrograssing having the second lowest score for criterion 2, effectiveness, in the MCA).

The sediment trapping structure SLM intervention (D) is situated higher up at leverage point 10 as it involves physical structures that need to be constructed and installed in order to mitigate soil erosion. This intervention for land rehabilitation influences the disturbed soil structure variable, affecting the whole 'gully effect' feedback loop (R9). Sediment trapping structures include stone lining and stone packs built in gullies to stabilise them and silt traps on bare surfaces to trap sediments. Twenty five local residents, trained as land conservation activists under the GEF5 Land Rehabilitation Hub, continuously work on these structures in the degraded landscape [51]. The mitigation of topsoil loss in turn reduces the loss of the organic matter and increases soil function. This change has the potential to shift both the R7 and R8 loops into virtuous cycles as soil functionality impacts grass cover, decreasing the overall extent of degradation and further topsoil loss. Sediment trapping structures face a similar scaling issue to that of agrograssing. At the paddock scale, sediment trapping structures can be effective, but the trapping structures require a lot of resources to be implemented throughout the catchment. There is an additional issue of high external funding reliance: as one project stakeholder noted in the MCA, although the material costs of the structures are minimal (because locally sourced materials are used), the community has stated that they will not continue making any structures without payment.

4. Discussion

4.1. Assessing the Extent of Crop Field Degradation (Research Question 1)

Our spatial analysis found that the majority of the mapped crop fields in Macubeni can be categorised as either "partly used" (47%) or "abandoned" (30%). Almost half of the total number of crop fields were highly degraded (47%), with 65% of the fields categorised as being highly vulnerable to further erosion. Other studies in the Eastern Cape of South Africa conducted in similar catchments found that abandoned fields were correlated with poor land management and/or a lack of land management strategies [54,55]. Some of the consequences of field abandonment include indigenous perennial vegetation species being replaced with arid condition shrubs, biophysical properties of the soil being compromised, and accelerated erosion [38,54]. Accelerated erosion, in turn, influences the overall land productivity. For example, farmers in Didimana, an area of the Eastern Cape adjacent to Macubeni with a similar historical, biophysical, climatic, and socio–political context, indicated that they lose more than 21% of their crops yearly due to erosion [56]. The reinforcing feedback loops conceptualised through and represented in the causal loop diagram (CLD) highlight the way in which multiple vicious cycles interact between land productivity, field abandonment, and degradation.

4.2. Assessing the Drivers of Field Abandonment in Relation to Degradation (Research Question 2)

Multiple studies have tracked the increase in abandoned fields and gully development in South Africa [8,9]. This is especially evident in rural, under-developed and poor areas, such as Macubeni [22,23]. Our systemic analysis of the Macubeni case developed the dynamic hypothesis that field abandonment is driven by diverse factors that include environmental (e.g., erosion and poor soil quality), socio–economic (e.g., land productivity and poor agricultural practices), and social factors (negative perceptions of agriculture and availability of labour) [9,26,47,48]. These diverse factors are inter-related, influenced by feedback effects, and are drivers of field abandonment and degradation that act on the system simultaneously and in interaction with one another, as illustrated in the CLDs (Figures 6–9). The combination of these factors and their dynamics demonstrates the value of a systemic approach towards understanding the complex interrelationship between field abandonment and degradation. The systemic interactions between variables also demonstrate the value of employing a leverage points-based analysis of sustainable land management (SLM) interventions, as discussed below.

4.3. Assessing Management Interventions in Relation to the Dynamics of Land Abandonment and Degradation (Research Question 3)

In this paper, we answered research question 3 (whether SLM interventions are capable of tackling the dynamics of land abandonment in relation to degradation) by firstly describing the SLM interventions operating in the case study (Section 3.3). In order to assess the efficacy of the SLM interventions as a means of tackling the dynamics of land abandonment, we used a multi-criteria analysis (MCA), which drew from stakeholders and project managers leading the SLM interventions (Section 3.3), and finally, we incorporated the MCA results in a synthetic discussion of the SLM interventions in relation to the systems leverage points (Section 3.4).

In summary, the SLM interventions encapsulated under the category of 'climate smart agriculture' scored the highest on the MCA, with grazing management interventions scoring the second highest (0.26 and 0.22, respectively—see Table 6). By our analysis, grazing management seeks to influence the system at the points of greatest leverage compared to the other SLM interventions (namely, 'the rules of the system', point 5 of Meadows' leverage points framework (see Table 7)). Climate smart agriculture, which scored highest on the MCA, seeks to influence the structure of information flows (leverage point 6), with the other interventions aligned with leverage points 9 and 10. This raises the question of what interventions or actions could possibly address the deeper leverage points that influence "the underpinning values, goals, paradigms, and mindsets that collectively shape the system" (i.e., leverage points 1–4) [33]. One such leverage point is the 'perceptions of agriculture' variable, which we discuss in the following sub-section.

4.4. Addressing Negative Perceptions of Agriculture

As shown in Figure 9, negative perceptions of agriculture influence the dynamics of land abandonment via three reinforcing feedback loops: (1) increasing negative perceptions of agriculture reduce available labour, increasing field abandonment and decreasing land productivity, forming the reinforcing cycle R2 (land productivity influencing perceptions); (2) increasing negative perceptions of agriculture also increase the likelihood of permanent abandonment, creating reinforcing loop R5 (perceptions influencing abandonment); and (3) increasing the likelihood of permanent abandonment is both a cause and effect of abandoned fields, via the reinforcing loop R4 (abandonment loop). Apart from the crucial variable of land productivity, the only other variable affecting perceptions of agriculture is 'demographic shifts'. Demographic shifts in Macubeni that affect land abandonment include ongoing urbanisation and a change in the fraction of youth alongside an aging older generation of existing farmers. At this stage, there are no interventions directly aimed at decreasing the negative perceptions of agriculture in Macubeni. A possible intervention is directly championing and promoting agriculture to the youth, which could serve to shift these three reinforcing feedback loops from their current, undesirable direction (where they are vicious cycles that perpetuate field abandonment and declining land productivity) towards a desirable direction in which *decreasing* field abandonment and *increasing* land productivity continually *reduces* the negative perceptions of agriculture, forming a virtuous cycle. Interventions aimed at shifting these negative perceptions address several leverage points. First, shifting the current dynamic of where field abandonment and land productivity reinforce in a vicious cycle, towards having these same dynamics reinforce as a virtuous cycle, addresses point 7 (the 'gain around driving positive [i.e., reinforcing] feedback loops') in the leverage points framework (Figure 1). Second, directly aiming to address the negative perceptions of agriculture is about engaging current paradigms and trying to change peoples' worldviews, which is positioned at point 2 (intent) in the leverage points framework (Figure 1). However, as Meadows [16] notes, "the higher the leverage point, the more the system will resist changing it" (p. 19). Sources of change resistance against proposed interventions aimed at improving peoples' perceptions of agriculture, drawn from the literature, include the overall strengthening of rural–urban connections [10]; increasing diversity in household incomes along with declining dependency on agriculture for income [12]; changes to agrarian identities [10]; and broader factors of globalisation, modernisation, and urbanisation [11]. These multiple sources of change resistance show why this particular challenge is likely to remain persistently problematic in the way in which it will continue to drive land abandonment and, in turn, degradation. Based on our analysis, we refer to this as one of two persistent challenges, the second of which we discuss in the following sub-section.

4.5. Using the Multi-Method Approach to Assess Spatial Prioritisation Strategies

As noted in Section 3.3, in the MCA component of this study, we assessed SLM interventions in terms of three criteria (cost, the reliance on external funding, and perceived efficacy of the intervention as a means of tackling land abandonment and associated degradation). In the synthetic leverage points-based analysis (Section 3.4), we discussed the MCA results in relation to the systemic conceptualisation of the dynamics of land abandonment. A persistent challenge that was raised is the difficulty of achieving and maintaining local-level commitment to the required SLM interventions based on evident positive change in relation to the scale of the challenges. As a historically disadvantaged and underdeveloped area, SLM projects in Macubeni are subject to resource constraints and high levels of poverty where the needs greatly outweigh the available resources. For this reason, areas must be prioritised based on a range of factors including cost, projected benefit, and feasibility. Here, we discuss how this study's combination of spatial analysis, systems analysis, and multi-criteria analysis, drawn together using the synthetic leverage points analysis, can be used to assess different spatial prioritisation strategies in a relatively simple way.

Crop fields could be prioritised using the spatial analysis by overlaying the three spatial layers for 'usage status', 'degradation level', and 'vulnerability status' to explore different prioritisation strategies. We compare and contrast two strategies here (A and B). Strategy A is to prioritise the worst-of-the-worst crop fields that are the largest contributors to degradation by focusing on the fields that are abandoned, with an existing level of degradation ranked as 'high' and with a 'high' vulnerability status for future degradation occurring (see Table 8). Figure 10a shows the location of these abandoned, highly degraded, and highly vulnerable fields in relation to the villages in the region and the GEF5 pilot areas. As an alternative, Strategy B departs from the rationale that it is better to focus on fields that are currently in-use or partly used, rather than abandoned, because there is more existing investment from the farmers' sides in the used and partly used fields. Instead of focusing on the used and partly used fields that are already heavily degraded, Strategy B could focus on fields that are moderately degraded, given that it is often quicker and more cost-effective to rehabilitate a landscape that is only partially degraded rather than one that is in a state of complete ruin. Finally, to have some degree of urgency and evidence of why rehabilitation efforts are required, Strategy B could focus on the moderately degraded fields that are rated as 'highly vulnerable' to future degradation. The number of fields meeting these criteria for Strategy B is shown in Table 8, with the relative location of these fields in relation to the villages in the region and the GEF5 pilot areas, shown in the map in Figure 10b.

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Table 8. Comparative scenarios for spatial prioritisation of interventions.

Usage Status	Degradation Level	Vulnerability Status	No. of Crop Fields (Fields)	Area (ha)	Avg Field Size (ha/Field)	% Area Covered (All Crop Fields)
(a) Abandoned	High	High	48	566.67	11.8	17.93
(b) Used + partly used.	Moderate	High	88	328.00	3.7	10.38

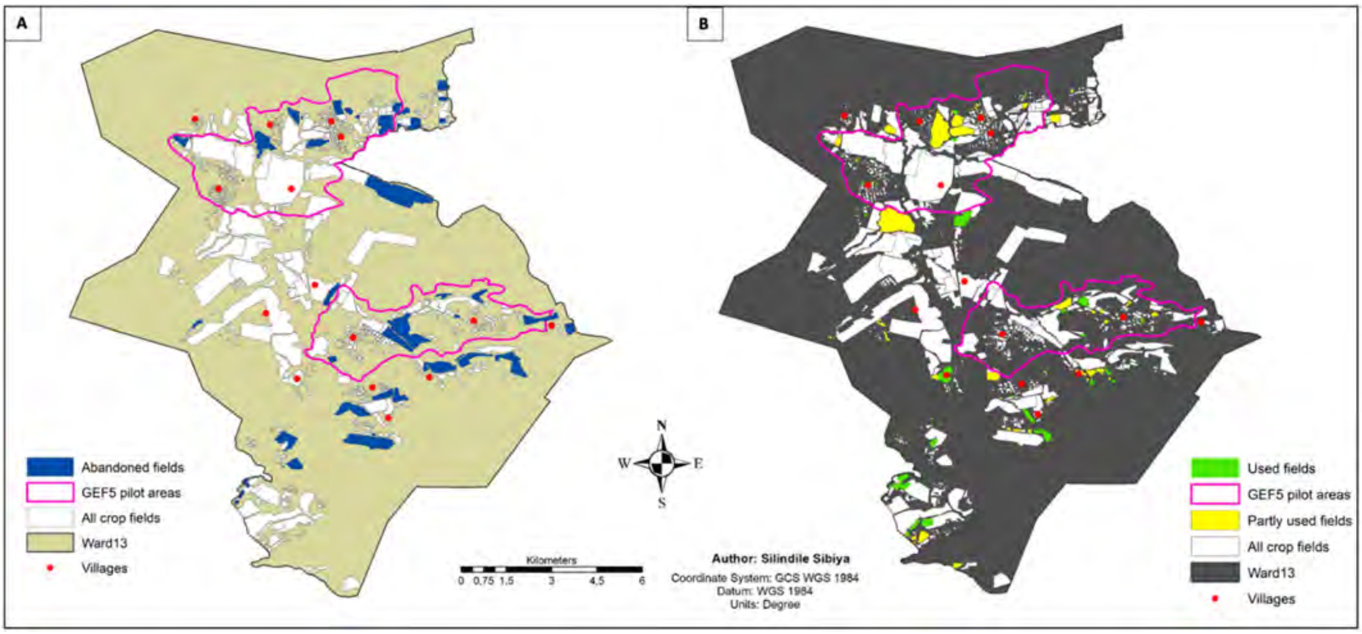

Figure 10. (**A**) = abandoned fields that are highly degraded and highly vulnerable; (**B**) = crop fields that are used, moderately degraded, and highly vulnerable (in green); and partly used, moderately degraded, and highly vulnerable (in yellow).

Figure 10. A = abandoned fields that are highly degraded and highly vulnerable; B = crop fields that are used, moderately degraded, and highly vulnerable (in green); and partly used, moderately degraded, and highly vulnerable (in yellow).

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Some immediate differences between the two strategies are evident in Table 8. With Strategy A (prioritising the abandoned fields), a small number of fields could be focused on, which are larger on average than the fields prioritised in Strategy B (an average field size of 11.8 ha for the Strategy A fields, versus an average of 3.7 ha/field for the Strategy B fields). This difference favours prioritizing fields as per Strategy A, given that economies of scale could be gained by having a fewer number of larger fields to rehabilitate for which resources could be pooled. Furthermore, focusing on the abandoned, heavily degraded, and highly vulnerable fields (Strategy A) could address an almost 80% greater area covered by all the crop fields than Strategy B (18% for abandoned fields, versus 10% for used and partly used). However, concerns could be raised that the abandoned fields are already too damaged to make rehabilitation economically viable and, given the fields' currently abandoned status, farmers could be less likely to buy-in to rehabilitation efforts.

Some immediate differences between the two strategies are evident in Table 8. With Strategy A (prioritising the abandoned fields), a small number of fields could be focused on, which are larger on average than the fields prioritised in Strategy B (an average field size of 11.8 ha for the Strategy A fields, versus an average of 3.7 ha/field for the Strategy B fields). This difference favours prioritizing fields as per Strategy A, given that economies of scale could be gained by having a fewer number of larger fields to rehabilitate for which resources could be pooled. Furthermore, focusing on the abandoned, heavily degraded, and highly vulnerable fields (Strategy A) could address an almost 80% greater area covered by all the crop fields than Strategy B (18% for abandoned fields, versus 10% for used and partly used). However, concerns could be raised that the abandoned fields are already too damaged to make rehabilitation economically viable and, given the fields' currently abandoned status, farmers could be less likely to buy-in to rehabilitation efforts.

The alternative strategy of prioritizing used and partly used fields (i.e., Strategy B) advocates for focusing on interventions on smaller parcels of land in order to benefit from synergistic interactions between the interventions. For example, a combination of agrograssing and sediment trapping structures could be deployed on the fields to control physical soil structure damage via reducing gullies and stabilizing grass cover, grazing management on the surrounding rangelands could then prevent free-moving livestock from exacerbating the existing gullies and from trampling the crop fields, and CSA practices could increase land productivity in sustainable ways, via increasing water availability and improving soil health via mulching and similar practices. The above examples of harnessing the interactions between these interventions would seek to influence leverage point number 7 (the 'gain around driving positive feedback loops') on Meadows' framework [16]. These positive (i.e., reinforcing) feedback loops are evident in Figure 9 as follows: agrograssing directly affects the grass cover stock; CSA practices address soil functionality, indirectly affecting the grass stock (loop R7); by reducing overgrazing, grass cover can be managed (loop R6); sediment trapping structures can reduce gullies, stabilizing soil (loop R9) and supporting soil functionality (loops R8 and R7).

All development projects operating in historically disadvantaged and underdeveloped areas like Macubeni in South Africa are subject to resource constraints and high levels of poverty where the needs greatly outweigh the available resources, requiring some degree of prioritisation. Prioritisation has many benefits, including increases in efficiency (for example, in a large-scale analysis of rehabilitation in the Brazilian Atlantic Forest, Strassburg et al. [57] showed how strategic prioritisation can triple the conservation gains while halving the costs). One of the main considerations between our prioritisation strategies was whether to focus on heavily degraded or moderately degraded fields. Our systemic analysis of the associated feedback loops supports Strassburg et al.'s [57] argument that, as degradation proceeds, more ecosystem benefits are lost, with the degree of loss of individual benefits increasing. The reinforcing (vicious) cycles continue to drive the system in a destructive direction, towards poorer land productivity, increased land abandonment, and increased degradation. All these factors mean that self-recovery (i.e., recovery without interventions) will be slower and the impact of external interventions (such as those driven by the GEF5 project) will be reduced. This can be mitigated by focusing on a smaller number of fields, as per Strategy B.

Despite the opportunities for positive synergies, focusing the full range of SLM interventions on a smaller number of fields could face pressure from both external sources (such as the GEF funding agency) and internal forces (such as community leaders) to spread the project resources as widely as possible. These pressures can be especially strong when evaluative criteria for a project emphasises 'number of people affected' rather than 'ecosystem change'. It is also important to recognise that ecosystem recovery time is typically longer than a project time frame: where a project may last 3–7 years, the ecosystem recovery of grasslands and wetlands, for example, can run into the decades [58,59]. This emphasises the challenges involved with stakeholders seeing evident change in the landscape from ecosystem restoration and other SLM activities as being a primary motivator to continue performing these activities after the lifespan of a project.

4.6. Study Limitations

This study was limited in a few different respects, which apply to all three of the core methods (the spatial, systems, and multi-criteria analysis) as well as to the systemic analysis. The aerial photographs used for the spatial analysis were from 2015. Although satellite imagery from 2020 was available (via Sentinel and Landsat), the pixel quality of this imagery was inadequate for the accurate mapping of crop fields (hence the choice of aerial photographs which, although older, were of a higher resolution and therefore more appropriate for field mapping). Ideally, aerial photographs captured between 2018 and 2021 could have been used to analyse changes over time (i.e., between 2015 and 2021). This is one possible area for future research.

A second study limitation was the fact that the systemic analysis remained at the qualitative level and that the conceptual understanding of the problem that was gained from developing the CLDs did not then form the basis of a quantitative simulation model [17]. The limitations of CLDs include that they can fail to capture the details of system change in terms of the amplitude/intensity of changes [15]. Qualitative modelling using CLDs is also limited in the way in which temporal dimensions can be assessed. There were multiple temporal dimensions raised in this study which, given the qualitative methodology deployed for the systems analysis, were not analysed in detail. These include the ecosystem recovery times associated with the interventions, which, if modelled quantitatively, could be assessed against a baseline 'self-recovery' period. A second temporal dimension is raised by the hypothesis that highly degraded fields have been abandoned for longer periods than others because, as per Koulouri and Giourga [60], longer periods of field abandonment (measured in years to decades) are associated with an intensification of soil erosion and gullies. The time associated with the fields' abandonment was excluded from the analysis but could be included in a future study. One approach for exploring the temporal dimensions of land abandonment in relation to degradation would be to develop a quantitative system dynamics (SD) model, using the qualitative systems model (as presented in this paper) for the initial conceptualisation. An SD model could simulate different combinations of interventions under multiple scenarios. Developing such a model is therefore another area for future research.

The value of including the Multi-Criteria Analysis (MCA) in this study lay in the way in which the different interventions assessed in the paper could be compared against one another, simultaneously considering economic, environmental, social, and technological aspects [44]. The MCA was also used as a way of structuring stakeholder input, using qualitative variables (such as stakeholders' perceptions of efficacy) alongside quantitative variables (the financial costs of the interventions). A limitation of MCA is that it cannot show that an action adds more welfare than it detracts. In this respect, MCA is inferior to alternative approaches, such as Cost Benefit Analysis (CBA), given that the former contains no explicit rationale that benefits should exceed costs [45,61]. For this reason, some scholars recommend caution in the use of MCA for policy formulation and policy analysis [41]. Future studies could benefit from a greater inclusion of analyses that account for relative costs and benefits of both acting and not acting (for example, by including the costs of *not* intervening in the landscape, which were not calculated in our study).

A primary limitation in the systems bounding of this study is the limited incorporation of climate change dynamics. In many parts of southern Africa, climate change is increasing the likelihood of both heavy rainfall and drought [62] (amongst other impacts) with multiple negative implications for the magnitude of soil erosion. As illustrated in the CLD in this paper, heavy rainfall directly increases soil erosion and gully formation; extended drought does the same thing indirectly via decreasing ground cover and vegetation (including grass cover) [29]. Case studies undertaken within Macubeni record that extended drought is perceived by community members to be one of the dominant drivers of land degradation [43]. The interactions between the multiple vectors of climate change, the specific human activities in Macubeni, and the dynamics of soil erosion, is a further area for future research.

5. Conclusions

Degradation in agricultural lands is one of the biggest environmental problems facing the rural regions of South Africa, with implications for land productivity, development, and livelihoods. This is especially true for communal areas such as Macubeni, in the rural Eastern Cape province, where there has been an increase in degradation and cropland abandonment for decades. In this study, GIS tools were used to determine the usage status and level of degradation in Macubeni and were coupled with qualitative systems modelling and a multi-criteria analysis to investigate the drivers of abandoned lands. The study found that most crop fields in Macubeni were either used or abandoned and that the abandoned lands were highly degraded. The increase in abandoned lands was attributed to a complex mix of socially, economically, and environmentally based drivers that are interconnected. The multi-method approach followed in this study enabled a combination of sustainable land management (SLM) interventions to be analysed in relation to the identified system's leverage points. We suggest that the innovative application of systems thinking through systems diagramming and leverage point analysis, combined with spatial analysis and a multi-criteria analysis, can assist with planning SLM interventions in similar contexts in the developing world.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land12030606/s1. Detailed results for the spatial analysis and the multi-criteria analysis, along with further methodological detail, can be found in the Supplementary Materials.

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