EXPLORING RANGELAND INTEGRITY TO SUPPORT ECOSYSTEM-BASED LIVELIHOODS IN THE EASTERN CAPE

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

BACKGROUND

Rangelands are multi-purpose and in Southern Africa they comprise of Grassland, Arid savannah, Semi-arid savannah, Thicket, Nama Karroo, Succulent Karroo, Desert, and Fynbos biomes, with different management practices. It is believed that the colonial past and subsequent management regime have combined to define the current rangeland status in Southern Africa. This study determined rangeland integrity in communal rangelands of the Tsitsa River Catchment, Eastern Cape province, South Africa using direct, destructive sampling and non-destructive methods, such as remote sensing and ground-based measurements, hydrological modelling, household interviews and workshops that facilitated traditional rangeland management.

AIMS

The following were the aims of the project:

1. To determine the productivity and extent of rangeland degradation in the communal rangelands of the Eastern Cape province.
2. To apply a spatially distributed hydrological model to estimate the catchment water balance and link this to ecosystem/rangeland productivity and community water supply needs.
3. To conduct a social assessment to determine community perception of rangeland changes over time, species change, and general ecosystem services from the rangeland and how these could be enhanced to improve their livelihoods.
4. To facilitate rangeland management practices (plans), propose forming livestock associations and reinstating traditional rangeland management practices.

METHODOLOGY

The study sought to determine rangeland integrity in communal rangelands of the Tsitsa River Catchment, Eastern Cape province, South Africa. To assess rangeland productivity, we used direct, destructive sampling and non-destructive methods, such as remote sensing and ground-based measurements, which have been implemented with varying degrees of accuracy. We conducted hydrological modelling to understand water balance in the studied catchment, conducted household interviews and workshops to understand the rangeland provisioning ecosystem services, and facilitated engagements on rangeland management.

RESULTS AND DISCUSSION

The study revealed that, dynamics in land cover and land use influence the ability of the rangelands to provide requisite ecosystem services. From a rangeland management perspective, land cover changes give insights into the availability of grazing land in an area. The landscape pattern changes were evaluated and landscape metrics suggests that the catchment was fragmentated, an indication of degradation. Although the land productivity dynamics maps indicated that the majority of the landscape

was stable, there is a distinct possibility of such areas to transition to productivity decline. This necessitates the need for judicious landscape management to increase beneficial landscape productivity. Most patches highlighted as of increasing in productivity are largely indicative of bush encroachment by both invasive alien plants and indigenous woody species. Therefore, this productivity may not be immediately beneficial to landscape users as it is symptomatic to degradation. We also conducted a grazing exclusion experiment and results suggest that long-term rangeland monitoring will be required to determine the potential for autogenic recovery of degraded rangelands. The water balance characteristics indicate the catchment maintains a consistent streamflow for most of the year. Only one month of no flow is experienced, undermining the availability of river water as a provisioning ecosystem service. The potential implications of a land cover change scenario, particularly the wattle invasion, indicate a largely negative impact on water balance. Scenario exploring the impacts of complete wattle invasion on water balance components indicates substantial changes, where evapotranspiration increases by 38%, groundwater recharge decreases by 60%, sediment yield reduces by over 40%, and catchment water yield drops by 22%. This impact extends to community water supply, groundwater recharge, and downstream contribution, potentially affecting riverine ecosystems. Despite reducing erosion and sediment transport, wattle invasion threatens ecosystem services provided by rangeland biodiversity, emphasizing the importance of robust wattle management. The rangeland provisioning ecosystem services were also reported threatened. This provided a direction on areas that could benefit from restoration when grazing management is implemented. Fire is reported as one of the major factor that threatens and undermines the provisioning of ecosystem services from the rangelands, while participatory mapping showed an illustration of the areas most vulnerable to providing provisional rangeland ecosystem services, where efforts to rest and restore rangelands should be directed. Lastly, rangeland integrity is significantly affected, impacting livelihoods in many ways in the catchment.

GENERAL

Rangelands productivity concerning provisioning ecosystem services findings is discussed. Aim 1, the productivity and extent of rangeland degradation in the communal rangelands of the Eastern Cape, is explored using remote sensing and ground-based measurements. Aim 2, a spatially distributed hydrological model, was developed to estimate the catchment water balance, links to ecosystem/rangeland productivity and community water supply needs. Aim 3, A social assessment of perception of rangeland changes over time, species change, and general ecosystem services from the rangeland and how these could be enhanced to improve their livelihoods, was conducted. Lastly, Aim 4, engagements on rangeland management practices with communities within the catchment, are ongoing.

CONCLUSIONS

The loss of rangeland cover significantly impacts livelihood in many ways in the catchment. Rangelands productivity and water balance are impacted negatively. Communal rangelands continue to experience transformation, suggesting the need for genuine community involvement and revamped extension packages on rangeland management project design. This cannot be overemphasised. This should enable the requisite integration of conventional indigenous technical science for co-knowledge production and management.

RECOMMENDATIONS

It is prudent to continue monitoring exclosures to determine improvements in grass production and grassland species richness. We hypothesised that more species are likely to emerge in the exclosures if monitored over time. One season may not provide conclusive data. After the first season, no statistically significant differences existed between soils from the inside and outside of exclosures. Even a principal component analysis could not separate the two soil groups. Resources permitting, soil quality could be reassessed after 3 or 4 seasons to decipher the influence of grazing exclusion on soil properties. Lastly, top-down government interventions should support the bottom-up approaches for rangeland management to create an enabling environment and strengthen sustainable rangeland management.

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ACRONYMS & ABBREVIATIONS

ACRU	Agricultural Catchment Research Unit
ANPP	Aboveground Net Primary Production
APAR	Absorbed Photosynthetically Active Radiation
BIOME-BGC	Biome-Biogeochemical Cycle Model
CARA	Conservation of Agricultural Resources Act
CARAIB	CARbon Assimilation in the Biosphere Model
CASA	Carnegie Ames Stanford Approach Model
DAFF	Department of Forestry and Fisheries
DEM	Digital Elevation Model
DFFE	Department of Forestry Fisheries and Environment
DPM	Disk Pasture Meter
DRDAR	Department of Rural Development and Agrarian Reform
ES	Ecosystem Service
ET	Evapotranspiration
fANPP	fraction of aboveground Net Primary Production
FAO	Food Agriculture and Organisation
FBM	Frankfurt Biosphere Model
GLO-PEM	Global Production Efficiency Model
GPP	Gross Primary Production
HRBM	High Resolution Biosphere Model
HRU	Hydrological Response Unit
KGBM	Kergoat Global Biosphere Model
LUE	Light Use Efficiency
MEA	Millennium Ecosystem Assessment
MUSCLE	Modified Universal Soil Loss Equation
NPP	Net Primary Production
NSE	Nash Sutcliffe Efficiency
PLAI	Postdam Land Atmosphere Interaction Model
SDBM	Simple Diagnostic Biosphere Model
SIB	Simple Interactive Biosphere
SILVAN	Simulation Land Vegetation ANNP Model
SWAT	Soil and Water Assessment Tool
TEM	Terrestrial Ecosystem Model
TURC	Terrestrial Uptake and Release
USA	United States of America
USGS	United States Geological Survey

CHAPTER 1 BACKGROUND

1.1 INTRODUCTION

Globally, rangelands cover around 54% of the earth's surface and support 30% of the world's human population (Yahdjian et al., 2015). Rangelands are characterised as land on which the possible native vegetation is primarily grasses, sedges and shrubs suited for grazing (Yahdjian et al., 2015). They provide and support various services, including food for millions of people, especially in rural and poor communities, habitat for domesticated livestock, and wildlife and support other functions such as the provision of wood, biodiversity, carbon storage and production of fuel. Many of these ecosystems and their beneficial services have been degraded. They are now threatened by various contemporary socio-economic concerns such as population growth, industrial development and global environmental concerns like overgrazing, land degradation and climate change (Khosravi & Escobedo, 2020). They are widely threatened and frequently overlooked as production sites of ecosystem services (Yahdjian et al., 2015).

In many parts of the world, rangelands provide several ecosystem services to both rural and urban areas, including food, fibre, water, clean air and natural medicine (Khosravi et al., 2019). Boone et al. (2018) showed that approximately 550 million people worldwide rely on livestock as one of their few or only assets, with 58 million living and deriving services from the rangelands. Similarly, in many rural areas of Sub-Saharan Africa, fuelwood is still the most important energy source for heating and cooking, and ecosystem services are usually needed for subsistence. Still, they can also bring financial income for farmers who sell products generated from rangeland ecosystem services (Scheiter et al., 2019). Since the release of the Millennium Ecosystem Assessment which puts human well-being as a central component (Mooney, 2005), the concept of ecosystem service has gained more traction in research, policy, and application (Wang et al., 2021). It can be a useful tool for informing policy-makers about using and managing rangeland resources (Slingsby, 2017). We base this project on ecosystem services (provisioning) generated by people in the Tsitsa River catchment such as wood, drinking water, fuel, grazing, and thatched grass, to mention a few as they serve as the foundation for most livelihoods and income sources making them the most important ecosystem services in communal rangelands (Dietze et al., 2019).

Driving this research is also a general belief that rangelands in the communal areas of the Eastern Cape province are degraded and may be unable to support ecosystem services for local people. Most local people depend on livestock production, and rangeland deterioration undermines the ability of the landscape to provide requisite resources such as water and forage. Tsitsa River catchment is in the Eastern Cape province in one of the strategic water resource areas. It faces degradation challenges related to soil erosion, alien vegetation infestation, and overgrazing resulting from continuous grazing. People in the catchment rely primarily on natural resources and urban remittances. The primary land use practices are livestock grazing, forestry, and crop farming. Most people in the area are not formally educated, and the poor availability of basic services such as extension services, health service centres and poor transport infrastructure have increased their vulnerability to shocks and stresses. While there has been an interest by the National Department of Water and Sanitation to build a dam in the catchment, it remains very prone to land degradation due to high sediment yields (Le Roux, 2018) and the Department of Forestry Fisheries and Environment, through the Tsitsa project has been looking at informing possible rehabilitation and restoration interventions to the degraded landscape to improve the lifespan of the dam. However, the management of rangelands to support ecosystem services and ensure sustainability of rehabilitated lands has been lacking and this project proposes to fill that gap.

Several other studies have been conducted in the area to improve the understanding of the landscape in various forms. For example, a regional modelling application was completed in the catchment under study (Le Roux et al., 2015). The project implemented a SWAT model to simulate sheet and rill erosion and resultant sediment yield. A gully erosion model supplemented the SWAT application. Le Roux et al. (2015) implemented SWAT hydrology at a regional scale, focusing on forcing the model's erosion component. Furthermore, Rowntree et al. (2019) looked at the opportunities for improving livelihoods through landscape greening in the same catchment while van Tol et al. (2014) conducted a study covering the larger Umzimvubu catchment to conceptualise a long-term monitoring project to capture the impact of the proposed dam on environmental, socio-economic and agricultural aspects. Lastly, van Tol et al. (2018) worked in Umzimvubu Water Project to conduct baseline indicators for long-term monitoring impact.

Against this dropback, the current approach sought to explore a more localised SWAT application with a specific focus on land cover impacts on water balance. Additionally, the current application focused on erosion impacts on rangeland and rangeland productivity, presenting a shift in focus from the previous application which focused on sediment yield impacts on reservoir storage loss. In addition to this, the Meat Naturally herding for health model through Lima development was explored where rangeland management practices yield positive benefits to livestock-based livelihoods, while rangeland functioning improved. We strongly believe that the rangelands must be managed sustainably to enable them to deliver ecosystem goods and services they used to deliver before. However, before any interventions aimed at landscape management are implemented, it is imperative to assess the state of the landscape to determine its potential to deliver services linked to rangeland production and water production. Therefore, these projects used biophysical and social dynamics for livelihood advancement in the socio-ecological systems to understand the landscape for improved ecosystem services. Within this project, we assessed rangeland integrity (productivity and degradation) using ecosystem assessment and modelling methodologies. We conducted a community assessment on perceptions of the rangeland ecosystem service.

1.2 PROJECT AIMS

The following were the aims of the project:

1. To determine the productivity and extent of rangeland degradation in the communal rangelands of the north-Eastern Cape province.
2. To apply a spatially distributed hydrological model to estimate the catchment water balance and link this to ecosystem/rangeland productivity and community water supply needs.
3. To conduct a social assessment to determine community perception of rangeland changes over time, species changes, and general ecosystem services from the rangeland and how these could be enhanced to improve their livelihoods.
4. To facilitate rangeland management practices (plans), propose the formation of livestock associations and reinstatement of traditional rangeland management practices.

1.3 SCOPE AND LIMITATIONS

The study used two traditional villages representing Tsitsa River catchment, where rural people derive rangeland ecosystem services. Evidence on the landscape shows a severe threat to these ecosystem services. The project focused on rangeland provisioning ecosystem services as derived by rural people. Due to limitations, the study could not conduct the household water use. However, scenarios to predict water availability were conducted though it did not mean the water was available for household use.

CHAPTER 2 INTRODUCTION

2.1 OVERVIEW OF RANGELANDS, DISTRIBUTION AND SOCIETAL VALUE

Rangelands are characterised as land on which the native vegetation is primarily grasses, sedges and shrubs suited for grazing (Joshi et al., 2013). Globally, rangelands cover around 54% of the earth's surface and support 30% of the world's human population (Yahdjian et al., 2015). Rangelands provide habitat for domestic livestock and wildlife and other ecosystem services such as wood, biodiversity, carbon storage and fuel production. Many of these ecosystems and their beneficial services have been degraded. They are now threatened by various socio-economic concerns, such as population growth, industrial development and environmental concerns, including overgrazing and climate change (Khosravi & Escobedo, 2020).

On a global scale, rangelands are differentiated into various categories, approximately 40.5% of the terrestrial area, meaning that rangelands comprise over 52.5 million km2 (Goode et al., 2020). This area can be further broken down into the different types of rangelands. Approximately 13.8% of terrestrial rangelands are woody savannas, 12.7% are open and closed shrublands, 8.3% are non-weedy grasslands, and 5.7% are tundra (Briske, 2017). However, varying drivers and disturbances result in rangelands transforming from one type to another worldwide. Some disturbances that influence the development of a specific range type include grazing, fire, diseases, and weeds, and they have always formed an important part of a rangeland's health and development.

In the United States of America, the varying rangeland types are a result of natural and human disturbances, which leads to them being dominated by the presence of tall-grass prairies in the eastern Central Plains, short-grass prairies in the Midwest and West and the mid-grass prairies in the Central Plains. Moreover, the environmental conditions have also resulted in varying amounts of forbs, trees and shrubs. On the other hand, rangelands in Texas are also mainly dominated by trees, shrubs and forbs where sagebrush dominates prairies in the west and grasses dominate the northern and middle portions of the country. Like Eurasian countries, open shrubs and non-woody grasslands dominate rangelands elsewhere. In contrast, Australia's rangelands are largely savannas along the open shrublands and coast in the interior. Except for tundra, South America has all types of rangelands with a diverse mixture of different classes along the lengthy western coast. Meanwhile, savannas dominate African rangelands with some open and closed scrublands. Figure 2.1 shows the global distribution of rangelands.

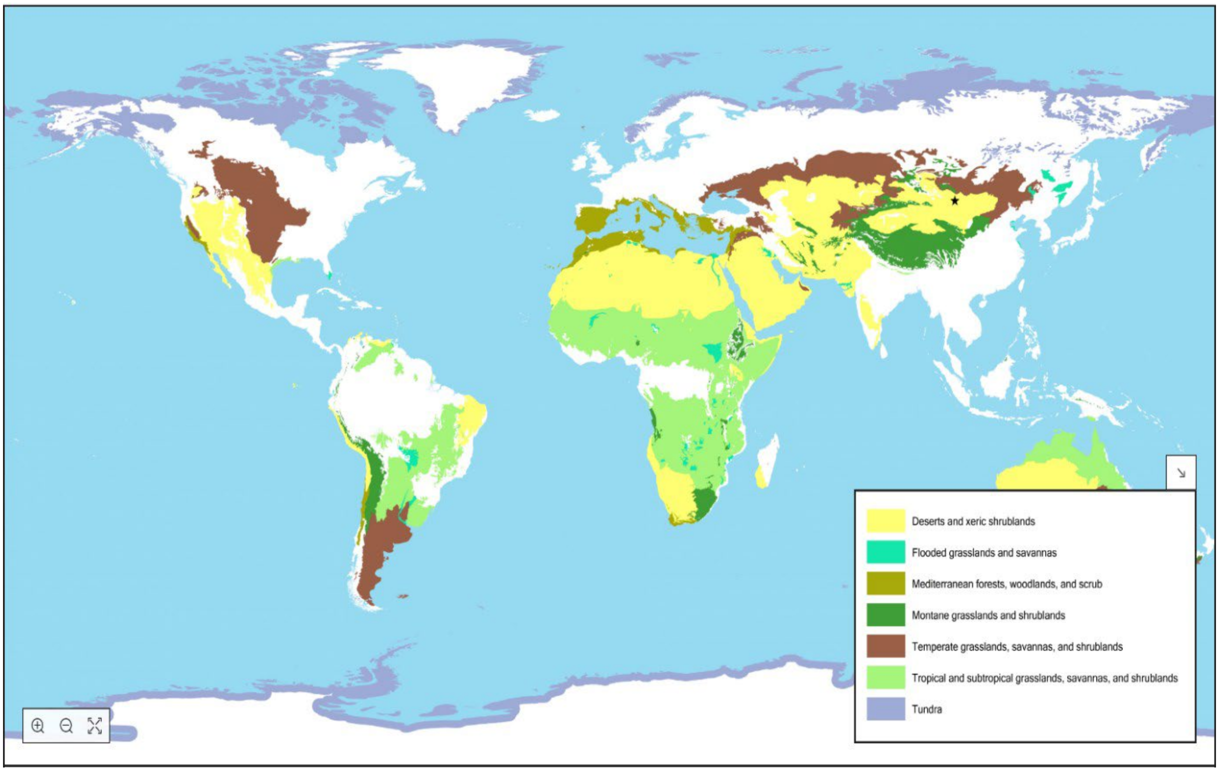

Figure 2.1. Global distribution of rangelands(Olson et al., 2001)

Importantly, rangelands contribute significantly to the provision of ecosystem services to both urban and rural people (Khosravi et al., 2019). For instance, Boone et al. (2018) indicated that approximately 550 million poor people worldwide rely on livestock reared on rangelands as one of their few assets, with 58 million people living in rangelands. Similarly, Scheiter et al. (2019) showed that fuelwood is still the greatest common source of energy for heating and cooking in Sub-Saharan Africa mostly derived from rangelands. These case studies show that many people use rangeland ecosystem services for subsistence and income from selling products derived from rangelands. Additionally, Bonne et al. (2018) urge that the reliance on ecosystem services from global rangelands is expanding, thus, understanding the sensitivity of deriving ecosystem services as societal benefits from these rangelands is essential.

The perception that commercial rangelands were more productive and better conserved compared to communal rangelands is a common belief stemming from colonial rule (Gusha et al., 2017; Palmer & Bennett, 2013). However, there is evidence that some communal rangelands are still productive, while others are degraded due to factors such as Invasive Alien Plants (IAPs) (O'Connor & van Wilgen, 2020; Gwate et al., 2021). Studies have found evidence of rangeland degradation and a decline in stocking rates in certain regions (Dean et al., 1995), but others have shown no evidence of degradation or overgrazing (Palmer & Ainslie, 2009; Gwate et al., 2021). It has been suggested that returning degraded rangelands to their background state would require active management interventions such as reseeding (Seymour et al., 2010; Falayi et al., 2022). Given the historical context of colonialism, communal rangelands in Southern Africa may have been degraded to some extent. Therefore, innovative rangeland management interventions that create an enabling environment will be crucial to improve production and reduce degradation in the communal sector.

Furthermore, the health of rangeland significantly depends upon features such as land cover (Montzka et al., 2008), as land cover changes significantly impact hydrology (Saddique et al., 2020). Therefore, interactions between rangeland productivity and the water balance are crucial to understand. Additionally, Zhao et al. (2013) recognise land cover as the primary driving force behind some of the hydrological processes, such as runoff, evapotranspiration, and base flow. Lastly, we report on fully integrated findings of exploring the rangeland integrity to support ecosystem services focusing on rangeland productivity, water balance and social assessment of the ecosystem services derived by local people in the Tsitsa River Catchment.

2.2 STATE OF THE RANGELANDS IN SOUTH AFRICA

Rangelands in South Africa comprise grasslands composed of perennial C_4 grasses at low altitudes and C_3 grasses at high altitudes. Elsewhere, a mixture of woody plants and perennial C_4 grasses characterise the Savanna Biome, while dwarf shrubs dominate the Karoo Biomes, with a greater abundance of grasses in the eastern Nama-Karoo Biome. With respect to the Albany Thicket, a mix of succulent and woody trees dominate, whilst the Indian Ocean Coastal Belt Biome is a mosaic of grassland, wetland, forest and savanna (Naidoo et al., 2013; O'Connor & van Wilgen, 2020). Although South Africa's rangelands are multipurpose, communal and commercial livestock production is the main activity (Naidoo et al., 2013). Consequently, rangelands are threatened by agriculture, settlement, mining, and invasive alien plants (IAPs) (Gwate et al., 2018; O'Connor & van Wilgen, 2020).

Various intensities and importance exist for livestock and wildlife ranching in the respective biomes (O'Connor & van Wilgen, 2020). The dynamics in rangeland management are strongly linked to the colonial past (Schwieger & Mbdzo, 2020; Samuels et al., 2021). The appropriation of productive land led to indigenous people being left with marginal land, resulting in overcrowding and hence the perception that communal rangelands are degraded has been entrenched. This dual system of livestock ranching, characterised by communal, commercial, and wildlife ranching, has persisted due to conflicting land tenure arrangements linked to historical factors. Freehold tenure allows for tighter control and regimented grazing systems, resulting in better rangeland management, while common property regimes have difficulty implementing rest and recovery periods, leading to degradation and inequality (Gusha et al., 2017).

The general perception in South Africa is that rangelands are degraded and may be unable to continue supplying requisite ecosystem services. For example, it is estimated that IAPs have reduced the value of livestock production by ZAR 340 million annually (O'Connor & van Wilgen, 2020). At the same time, IAPs have transformed some rangelands into novel systems, resulting in communities embracing these species and exploiting the opportunities they provide (Gwate et al., 2016). In addition, a qualitative survey by Dean et al. (1995) revealed that 35% of rangelands in south-western South Africa (Karoo) were in a poor state and degraded, leading to a decline in stocking rates. Consequently, quantifying degradation has been challenging for the multipurpose rangelands in South Africa. However, literature suggests that the rangelands are incompletely run down. For example, in a long-term study, Palmer and Ainslie (2009) found no evidence of drastic change toward degradation or overgrazing using the water use efficiency metric in the rangelands in the former Transkei. At the same time, it has been demonstrated that returning overgrazed rangelands to their background state will be difficult unless active management interventions such as reseeding are undertaken (Seymour et al., 2010). This was also affirmed by Falayi et al. (2022), who reported that there has been a steady degradation of local rangeland resources since apartheid and that a return to effective governance alone will not necessarily result in improved rangeland condition in parts of the Eastern Cape province unless active interventions such as reseeding and building individual and group agency are implemented. This suggests that rangelands previously exposed to overgrazing were unlikely to recover to background levels, indicating that most rangelands, particularly in the former homelands, could have deteriorated. In addition, it is often believed that commercial rangelands were more productive and conserved since colonial rule favoured this sector (Gusha et al., 2017; Palmer & Bennett, 2013). At the same time, some studies suggest that the rangeland production in the commercial land tenure system was no better than in the communal (García et al., 2013; Gwate et al., 2021). Tokozwayo et al. (2021) also reported that although increasing grass species suggested rangeland deterioration, the abundance of palatable woody plants suggested great potential for goat production in the Eastern Cape province.

A dual system of livestock ranching has persisted in South Africa due to conflicting land tenure arrangements linked to colonial history (Mani et al., 2021), characterised by communal livestock ranching on leasehold tenure property on one hand and commercial livestock and wildlife ranching on land under freehold tenure. Generally, under freehold tenure, the grazier/rancher can exercise tighter control over the type, number and grazing duration of livestock. This has resulted in the implementation of regimented grazing systems that provide rest periods and post-grazing recovery. Under common property regimes, these rest and recovery periods have been more difficult to implement. This duality has resulted in rangeland degradation in the communal sector and undermined livestock production, entrenching inequalities (Gusha et al., 2017). These contrasting land tenure arrangements result in conflicts.

To reduce these conflicts, there was a need to incentivise communities managing livestock under common property arrangements to participate in other livelihood practices such as large mammal conservation programmes and, at the same time, economically benefit from wildlife tourism, sport hunting, and the legal sale of animal by-products (Holechek & Valdez, 2018). Several such models have been successfully applied in Zimbabwe, Botswana, and Namibia and such community-based wildlife conservation programmes tend to promote the most efficient use of rangeland forages and landscapes while diversifying income and lowering the risk (Holechek & Valdez, 2018). Therefore, the literature suggests conflicting views on the state of rangelands in South Africa. However, the colonial past and subsequent management practices seem to have formed the basis of rangeland deterioration. Most of the studies on rangeland conditions have been sectoral and lacked the reality of the complexities of the multiple-purpose use of the rangeland system. Hence, a comprehensive study combining natural and social sciences is required to better understand the rangeland's condition. We need to understand the extent of this 'degradation' from multiple perspectives to appreciate various processes that modulate the state of rangelands. This understanding will enhance the development of innovative ways to promote the multipurpose use of rangelands' integrity.

2.3 RANGELAND MANAGEMENT SYSTEMS IN SOUTH AFRICA

In South Africa, about 72% of the total land area is suitable only as rangelands for game farming and livestock production because of low precipitation (Tainton, 1999). Commercial livestock ranching, game ranching and communal livestock ranching are the three main rangeland management systems found in South Africa, these management systems differ in terms of their animal diversity, management structure, products and how the grazing resource is managed. In a South African context, commercial livestock farming is a well-developed industry in which red meat contributes approximately 12% to the gross value of South African agricultural products. On the other hand, the game ranching industry has been growing fast by about 6,75% every year since 1993 (Tomlinson et al., 2002). Importantly, the game ranching's major focus has been on ecotourism, venison and trophy hunting, while the most important South African rangeland users are communal livestock ranchers. Many rural South Africans maintain livestock on communal lands to compensate for low and non-existent income. The income generated from livestock production is often insufficient and is usually supplemented by livestock ranching income. In communal areas, livestock owners usually do not sell their animals in the markets. Consumption occurs occasionally, and this is usually for traditional slaughtering. Surplus livestock are occasionally sold to cover large incidental payments such as academic fees.

In most wildlife and commercial rangeland enterprises, managers have attained some level of tertiary education. Decision-support services, for example, research institutions and government agencies that deal with agriculture-related issues have a long history of providing extension and support services to commercial ranchers. However, communal livestock management has largely been based on the traditional rangeland management system, with livestock owners lacking formal training in rangeland management and general animal husbandry. This lack of formal education has long been documented as the major cause of the mismanagement of communal rangeland; hence, they are now perceived to be highly degraded and cannot sustain livestock production (Behnke & Scoones, 1992). However, it has been long argued that the lack of education cannot be labelled as the major cause of rangeland deterioration in communal rangelands, as one of the complications in these systems is the fact that they are a common resource for all communal people with no one single person responsible for managing them. One of the major challenges with a common resource property discussed by Hardin (1968) is that no one often takes responsibility for any change or damage in the system.

Against this history, comparative studies have been conducted on rangeland management systems, looking at vegetation structure, dynamics, and composition and presenting arguments for the main reasons for degradation in the communal sector (Ward et al., 2000). As the impacts of running livestock in common property, some individuals end up deriving all the benefits by overstocking and overusing the common resource. The consequences affect everyone who derives benefit from the resource. Because of this practice, livestock numbers continue to grow excessively and eventually reach their grazing capacity, leading to degradation. However, this phenomenon has been criticised, and it has been urged that the communal rangeland system is incompletely out of rules, as livestock owners may regulate their livestock numbers to a certain extent though it is unlinked to grazing management. Table 2.1. shows how different management systems have different carrying capacities depending on the objectives of how the system should be managed in terms of ecological and economic benefits (Scoones, 1993). Based on ecological and economic benefits, exceeding the carrying capacity of a rangeland system does not automatically equate to rangeland degradation as competition for feed by livestock does not occur at the same time the vegetation changes occur. This argument is fuelled by the fact that degradation in both semi-arid and arid rangelands caused by high stocking rates can be reversed by rainfall events (Tainton, 1999).

Table 2.1. Differences in management structure, production, animal diversity and grazing resources between management systems (Scoones, 1993).

Variable	**Communal system**	**Commercial system**	**Wildlife management system**
Management structure	Multiple managers	Single manager	Single manager
Animal diversity	Many different species	Single species	Many different species
Management of a grazing resource	Continuous grazing, diverse vegetation.	Rotational grazing, Uniform vegetation.	Continuous grazing, diverse vegetation
Products	High quantity, big diversity of products mostly for subsistence use.	High quality, single product for domestic and international markets.	High variety, strong healthy big animals for trophies and ecotourism

2.4 RANGELAND ECOSYSTEM SERVICES

Rangeland ecosystem services are the benefits obtained directly or indirectly from the ecosystem (Yahdjian et al., 2015, Choruma et al., 2019). Rangeland ecosystem services are divided into four categories: provisioning, including medicinal resources, wood, food and services that control agricultural pests, air purification and contribution to climate stability and water (Figure 2.2). Supporting ES includes ecologically processed dependent services such as primary production and nutrient cycling. Regulating ES includes carbon sequestration, natural floods control and prevention of soil erosion and cultural ecosystem services, including recreational, inspirational and intellectual activities. However, since the conceptualisation of the ES, the focus has changed from just describing the processes involved in the delivery of a single service to approaches involved in analysing the capacity of nature to produce multiple ES.

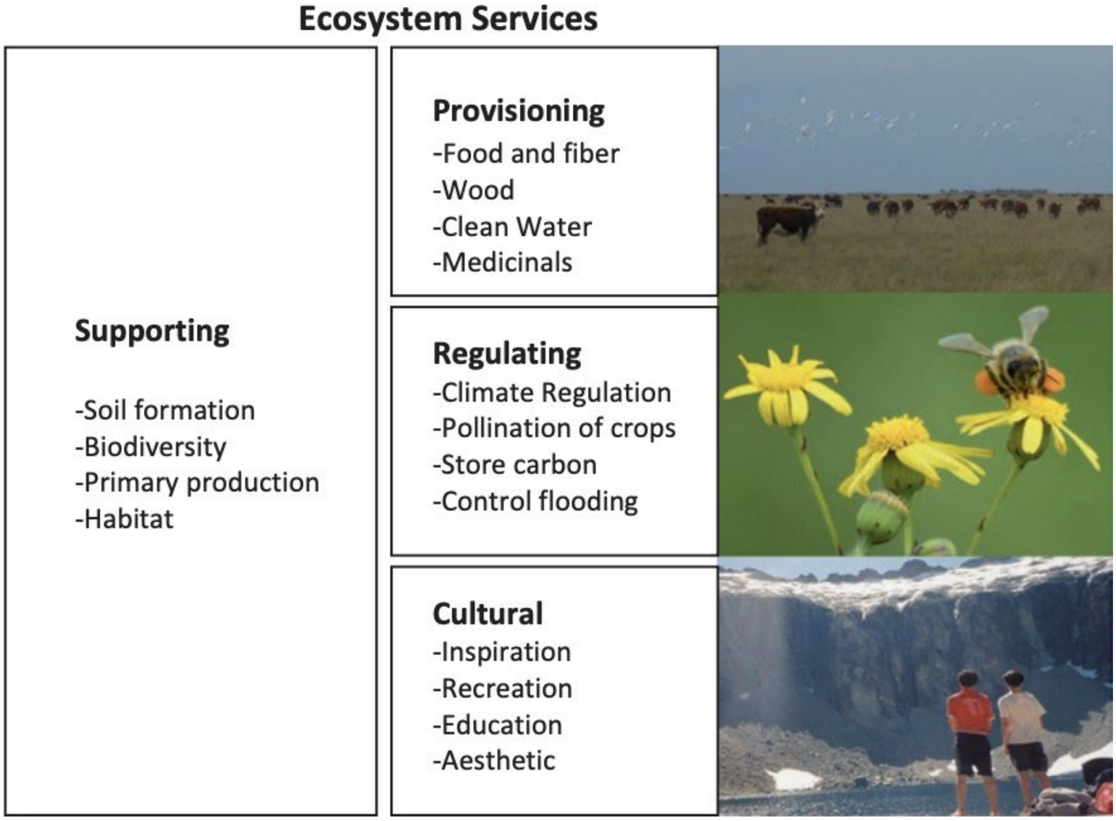

Figure 2.2. Categories of ecosystem services as classified by the Millennium Ecosystem Assessment (MEA, 2005).

A great variety of ES is produced from rangelands across the world. However, only a few get access to market value chains (Sala & Paruelo, 1997). Although products like meat and wool produced from rangelands have market value, other services such as cultural, regulating and supporting ES mostly do not have any market value, although they can be estimated indirectly. In addition, the economic valuation of ES has also been a frequent target of research (Gomez-Baggethun et al., 2010).

Although the science of ecosystem services has developed rapidly, the focus remains largely on the supply of ecosystem services and has overlooked the demand for ES by humans. This overlooked component represents the other side of the ES equation of supply and demand related to the social benefits. Tallis and Polasky, (2011) argue that the consumption and utilisation of ES resources supplied by the ecosystem depend on the environment's ability to produce them and the societal value placed on those resources and services. On the other hand, the demand for ES among people could influence the delivery of those ES from the rangelands (Lamarque et al., 2011). Rangelands are ideal for analysing the supply and demand for different ecosystem services because of the various ES they provide to people. Although rangelands are broadly threatened by various factors like climate change and human activities, they continue to provide abundant ES.

2.5 CATEGORIES OF RANGELAND ECOSYSTEM SERVICES

The ecosystem services that the rangelands provide are categorised into four types as defined by the MEA (2005) in the previous section. This section gets deeper into detailing the different ES, providing extensive examples. The demand for provisioning ES in rangelands is usually higher than the supply. However, this may be context-specific as, in other cases; supply exceeds demand, depending on how much the service is being used. For example, water for irrigation in the rangelands is required during specific periods when water is scarce, so the supply of provisioning services from rangelands changes at different time scales (Adler et al., 2005), depending on the income of the people deriving the services, education and location of their residency (being urban or rural dwellers) (Yahdjian et al., 2015).

The services that people benefit from regulating ecosystem processes, including air quality, climate regulation, soil erosion and water purification, are not easily measured by supply and demand from the rangelands but can be quantified. A large quantity of carbon is sequestered by the rangelands, primarily into the soil (Sala & Paruelo, 1997). However, in terms of carbon, the demand is usually higher than the supply as it cannot offset actual carbon emissions from human activities (Tallis & Polasky, 2011). Rangelands provide an important area for carbon sequestration, although carbon storage may be lower than in other ecosystems like wetlands (Reynolds et al., 2007). In addition, rangelands account for a significant fraction of the global carbon cycle and most of the inter-annual variability in the global carbon sink (Ahlström et al., 2015).

The non-material services obtained from the ecosystem by people, referred to as cultural ecosystem services, include recreation, knowledge systems, religious and spiritual values and cultural diversity, and are both consumptive and non-consumptive. These services relate to human experiences and activities like wildlife hunting, tourist ranching, and traditional lifestyles. The demand and supply for these services is also context-specific depending on how people value and practise them.

Lastly, rangeland services are necessary to produce all other ecosystem services, such as processes that maintain biodiversity to produce goods or cycle nutrients and are referred to as supporting ES (MEA, 2005). At the global scale, the supply of supporting ecosystem services is higher than the demand. Still, human use does not directly apply since, by definition, supporting services are not directly used by people, even when they influence the supply of provisioning, regulating, and cultural services. In a rangeland context, they include nutrient cycling, primary production and biodiversity, presenting a large storehouse for species, genetic and functional diversity. Several factors affect the provisioning of supporting ES such as overgrazing, weed invasions, energy extraction, and urban development and later result in land degradation, which has a higher impact on the ability of the ecosystem to provide services to people (Herrick et al., 2013).

2.6 PEOPLE'S PERCEPTIONS OF RANGELAND PROVISIONING ECOSYSTEM SERVICES

Local people's perceptions are critically important when assessing the balance between the demand and supply of ecosystem services. Sustainable land management depends on balancing the supply and demand for ecosystem services among various land users (Yahdjian et al., 2015). Local users' perceptions of ecosystem services are characterised by human values, attitudes, beliefs, behaviour, and demographic characteristics like gender, education, and age (Liu et al. (2022). For instance, Liu et al. (2022) addressed the significance of age in determining perceptions of ecosystem service benefits when reporting that older persons have more opportunities to utilise natural resources and are more likely to obtain ecosystem service benefits. In a field survey by Liu et al. (2022) conducted in two rural areas of China, it was indicated that 32% of the respondents were residents who were school graduates between the ages of 18 and 27 years; these residents were either found to be working or studying in the cities and were less likely to obtain ecosystem services than older people. The level of education also provides a better determination of the perceptions of ecosystem services benefits than other characteristics, as the effect of age is partly mediated by education (Asah et al., 2014). Perceptions regarding people's attitudes, values, beliefs, preferences and behaviours depend on ES local people use and the benefits they receive from the ecosystem (Liu et al., 2022). For instance, Leroy et al. (2018) report that the owner has valued resources and preferences, such as the type of grass; preference for their livestock, impacting livestock owners' perceptions of ecosystem services in grazing regions. Martín-López et al. (2012) also conducted surveys in the rural areas of Spain, uncovering social preferences in the ecosystem with randomly selected individuals. The perceptions of these individuals were analysed based on various ecosystem services beneficiaries, such as local inhabitants, environmental technical experts, and visitors. Their perceptions of regulating services were identified as the most prominent factor in their respective areas at 44% of respondents. Cultural services followed it at 33% of respondents, and provisioning services at 23%, highlighted by 11% of respondents from the 23% that of all the benefits provided by provisioning services, grazing lands are the most perceived areas by livestock owners.

2.7 SUPPLY AND DEMAND FOR RANGELAND ECOSYSTEM SERVICES

The ability of specific rangeland to generate ecosystem goods and services within a certain period is referred to as the supply of ecosystem services (Yahdjian et al., 2015). Ability in this context refers to the generation of the used set of ecosystem services. As a result, it differs from the potential supply of ecosystem services in a specific ecosystem, which would be the theoretical highest yield of specified services (Hruska et al., 2017). On the other hand, demand refers to the amount of each ecosystem service currently used in a specific area over a given period (Burkhard et al., 2012). The ecosystem services supply is mostly influenced by biophysical elements like soil, climate, and previous land uses, while the demand for ecosystem services is influenced by the desire and value of the services by beneficiaries (Yahdjian et al., 2015). Human consumption of rangeland resources and use of rangeland services depend on the rangeland's capacity to produce services, society's values and needs to be placed on those services (Yahdjian et al., 2015). The demand for ecosystem services fluctuates among social beneficiaries and groups interested in ecosystem services, such as livestock owners, and crop farmers, to mention a few. (Wang et al., 2019). Supply and demand of ecosystem services are important to both rangelands and people because they are used to navigating the deterioration of the ecosystem's ability to produce desired and valuable ecosystem services for human consumption and the amount of ecosystem services consumed by people in a given period (Burkhard et al., 2012).

2.8 GENDERED PERCEPTIONS OF RANGELAND ECOSYSTEM SERVICES

The available literature on ecosystem services shows that gender remains a critical gap (Cruz-Garcia et al., 2017). This suggests that many ES valuation studies do not consider gender. Failure to consider gender may result in mitigation and adaptation initiatives that do not meet the needs of both females and males (Cruz-Garcia et al., 2019). Only 5 out of 49 case studies focused on gender. While gender is likely to be a key determination of how people benefit from ecosystems, Cruz-Garcia et al. (2017) and Schreckenberg et al. (2018) report four hundred and sixty-two papers on ecosystem services and well-being. The absence of gender in these perceptions leaves ecosystem service frameworks ill-aligned with global development's central concerns of equity, justice, and knowledge. Ecosystem services tend to be gender-based, which implies that females and males benefit differently from the ecosystem (Fortnam et al., 2019). Gender plays an important role in how people perceive and interact with their surroundings and frequently impacts how environmental resources are used, managed, accessed, and controlled (Cruz-Garcia et al., 2019). For example, according to Yang et al. (2018), males have a higher valuation for firewood and charcoal for profit-earning purposes and timber harvesting for fencing and building, while women value fresh water and medicinal products. Fortnam et al. (2019) noted that women value rangeland ecosystem services that benefit the households directly, like firewood collection for cooking and heating. Both Yang et al. (2018) and Fortnam et al. (2019) agreed that the provision of food is not gendered. Both females and males engage to a similar extent when it comes to providing food. For example, according to Djurfeldt (2018), maize markets in all countries, except Zambia, are not physically divided by gender; female and male farm managers sell maize within the village. Other studies have found that women are more vulnerable and reliant on ecosystem services than males due to females having to sustain households (Porsani et al., 2020, Perez et al., 2015). This is also because social and cultural norms restrict females from migrating in many rural societies; males are more likely to migrate, resulting in a phenomenon of left-behind females leading their households (Choithani, 2020). Males are also more likely to participate in activities that require travelling away from their homes.

In contrast, females are limited to spaces close to their homes due to household duties and taking care of children (Shackleton et al., 2020). The left-behind female-headed households in some communal rangelands can face significant challenges in accessing ecosystem services due to a lack of security of land rights (Schreckenberg et al., 2018). In some societies, women face double exclusion due to a lack of agricultural assets and limited access to alternative sources of income outside of agriculture (Djurfeldt, 2018). Gender differences and relationships must be considered to achieve sustainable development and avoid the costs of environmental and economic change that undermine gender abilities and social sustainability (Cruz-Garcia et al., 2019).

2.9 INFLUENCE OF RAINFALL PATTERNS ON RANGELAND PRODUCTIVITY

The health and productivity of rangelands are strongly coupled with precipitation. This close coupling has been demonstrated widely (le Houerou & Hoste, 1977; Gamoun, 2016). Hence, climate change will negatively influence rangeland production and inadvertently affect the food production system (Godde et al., 2020). This necessitates context-specific responses to changes to ensure adaptation to climate change and other future uncertainties. It has also been demonstrated that climate variability leading to more droughts impairs rangeland production and inadvertently increases poverty in Ethiopia as livestock production systems change in response to changes in plant communities (Kassahun et al., 2008). Although changes in botanical composition may be strongly influenced by rainfall variability, stocking rate had an additional effect over time (Fynn & O'Connor, 2000). This suggests that rangeland systems can display non-equilibrium and equilibrium behaviour as abiotic and biotic factors play a role in production (Vetter, 2005). Rangelands' gross primary productivity is very sensitive to changes in growing season precipitation. For example, widely distributed growing season precipitation and warm winters result in higher gross primary production (Liu et al., 2022). If the optimum temperature for production prevailed, the relationship between precipitation and rangeland production should theoretically be linear since moisture availability improves production (le Houerou & Hoste, 1977). However, emerging evidence suggests that the relationship between rangeland production and rainfall is often unimodal, indicating critical precipitation thresholds for optimum production (Gwate & Ndou, 2022; Sun & Du, 2017). Hence, it is important to understand these thresholds in South Africa in the context of climate change. It will also be critical to have a deeper understanding of the rangelands' rainfall or water use efficiency, which can help understand current production and provide insights into production under climate change.

2.10 INTERVENTIONS TO IMPROVE THE STATE OF RANGELANDS

During colonial rule (prior to 1949) and under apartheid (1949-1994), South African government policy on rangeland was skewed against the black majority. It is well established that the government used the sustainable management of rangelands as a conduit for funding freehold farmers to remain on the land during those periods. In contrast, fewer resources were provided to manage livestock on common property (Peden, 2005). This could partly explain perceptions that communal rangelands are degraded. Although government policy in the post-colonial era focused on those who lived in communal areas, Peden (2005) suggests that there has not been comparable investment in managing rangelands compared to commercial rangelands during colonial rule, with a focus on housing and water provision. However, government policy has largely prioritised private land rights and commercial land uses, seeking to dismantle the racial divide between the white commercial farming areas and the ex-Bantustans by allocating former white farms to black farmers, neglecting the potential role of livestock production on the commons (Hall & Cousins, 2013). This means the potential for sustainable management of communal rangelands has not been addressed effectively.

Nevertheless, responsive measures have been implemented, for example, the African National Land Care Programme, launched in 1998 by the National Department of Agriculture, to promote ecologically sustainable approaches to land management (Peden, 2005). Sustainable rangeland management in the communal sector systems requires the presence of government institutions that can manipulate ecosystems by strictly regulating the use of grazing resources and by applying appropriate management actions. Still, these were lacking in the communal sector (Palmer & Bennett, 2013). Consequently, it has been suggested that communal rangelands should be viewed as a complex sociological system; hence, interventions to address these rangelands should be centred on complex systems modelling with an inclusive group of stakeholders that holds potential for realising such policy (Allsopp, 2013). In addition, the government is encouraged to conclude the land tenure impasse to reduce disputes around tenure in the country to allow responsive community-based institutions to take charge of local land administration to enhance sustainability (Bennett, 2013). However, it has been noted that current land use policies in South Africa designed to redress historical land injustices and improve rural livelihoods are indirectly connected with those prioritising the protection of ecosystems and biodiversity or climate mitigation (Mani et al., 2021). Therefore, the need for integrated approaches cannot be overemphasised.

Meanwhile, the biggest government public works programme under the auspices of the Working for Water programme (Turpie et al., 2008) is also critical in rangelands management as it aims to clear river catchments of invasive alien plants to improve ecosystem services (O'Connor & van Wilgen, 2020). Grazing management initiatives such as rotation grazing and high-density grazing have been introduced. Still, these are unlikely to restore rangelands to a background state unless active interventions such as reseeding are conducted (Seymour et al., 2010). Many studies have explored cost-effective ways of restoring functional native ecosystems following invasion by alien plants. Trends in non-native species control in South Africa during the 1980s and 1990s suggested that carefully planned intensive clearing programmes could contain and possibly even eradicate aggressive alien species if adequate funding is allocated (Moll & Trinder-Smith, 1992). Gaertner et al. (2012) found that the diversity and evenness of native plant species increased significantly after restoration at three study sites in the Western Cape, South Africa. In contrast, the cover of alien plants decreased significantly, confirming that active restoration was successful. However, Holmes et al. (2020) reported that autogenic recovery could be relied upon in areas with low to medium-density invasions and for dense invasions where diversity of growth forms persists in aboveground vegetation and/or in soil-stored seed banks. Fill et al. (2017) found that reliance on passive restoration had not yet resulted in full recovery of the natural vegetation over 13 years of monitoring an area cleared of non-native plants in a mountain catchment. Hence, there was a distinct possibility of the cleared area reverting to a more densely invaded state in the event of a funding reduction. The need for follow-up treatments to effectively restore landscapes cleared of non-native plants has been acknowledged (Mostert et al., 2017; Pretorius et al., 2008).

Active restoration of densely invaded sites may only be justifiable if the target area is in a region of high conservation priority and if recovery of biotic and abiotic thresholds has not been crossed (Holmes et al., 2020). Clearing off some non-native plants on landscapes results in quicker positive responses on some species than others. For example, in their autogenic recovery assessment after clearing non-native plants, Mostert et al. (2017) found that the *Acacia* invasion caused a greater change in biodiversity and vegetation structure than pine plantations. However, the financial analysis showed that income from flower harvesting following active restoration consistently outweighs income following passive restoration, indicating that active restoration can be effective and financially feasible compared to passive restoration, depending on the density of invasion (Gaertner et al., 2012). In addition, active restoration will be required in sites with low spontaneous succession potential. To improve restoration and alien control processes improved strategic planning, prioritisation and criteria for assessing success protocols should be developed to optimise resource use and to enhance the adaptive management of non-native plants (Richardson & Wilgen, 2004; Fill et al., 2017; Holmes et al., 2020). Over and above, rangeland restoration initiatives were expensive and will be nuanced by global change (Bourne et al., 2017).

2.11 POLICY ISSUES AND DIRECTIONS

The formal instrument for protecting rangeland resources in South Africa is the Conservation of Agricultural Resources Act (CARA) (Act 43 of 1983). This law, as was set down by the then Department of Agriculture, Forestry and Fisheries (DAFF), now the Department of Rural Development and Agrarian Reform (DRDAR), was based on agricultural resource protection, providing a conduit for the drought relief financial support to farmers who were complying with the recommended rangeland carrying capacity as set by the department (Palmer & Bennett, 2013). To be eligible to receive financial support, the participating farmers have had to demonstrate that they were managing their farms within the government's regulated carrying capacity norms and standards. However, a change in government in 1994 saw a shift towards farmer developments in communal areas. CARA-supporting regulations could no longer be applied in areas under the communal tenure system, as resources were already perceived as degraded.

On the other hand, it was challenging for the government to use available instruments from farmers who complied with the regulations without facing any legal issues. Related to this was that no big efforts were made pre-1994 to establish carrying capacity norms in the former homelands as they were regarded as areas outside the Republic of South Africa (Palmer & Bennett, 2013). Furthermore, implementing CARA proved impossible, as there were no tested models of net primary productivity, which could be used to regulate land under communal tenure and herd size. Palmer and Bennett (2013) further urge that one of the possible reasons for this collapse and poor adoption of CARA in the communal tenure system is the lack of collaboration from livestock owners and the reluctance to apply and enforce bylaws set by the traditional committees.

CHAPTER 3 EXPLORING THE EXTENT OF RANGELAND DEGRADATION IN THE TSITSA RIVER CATCHMENT

3.1 INTRODUCTION

Grassland covers approximately 40% of the global terrestrial surface and plays a significant role in regulating the energy flow in the biosphere and material circulation while maintaining the terrestrial biodiversity and providing food production, carbon storage and water supply (Piao et al., 2009). Furthermore, rangelands also provide non-material benefits, such as education opportunities, recreation, and livelihoods to both humans and animals (Bardgett et al., 2021). In addition, rangelands help improve water quality through reduced sediment yields in the rivers and reduce soil erosion while providing flood control and reducing the impact of climate change (Piano et al., 2009). However, human interference in these grasslands has had a negative impact and approximately 49% of the grasslands globally are experiencing a major decline in vegetation cover and biodiversity (Bardgett et al., 2021).

Exploring the mechanism of rangeland degradation and the consequences it has on biodiversity loss has been challenging as the effect of livestock overgrazing is recognised as one of the most important drivers (Zhang et al., 2021). It is expected that rangelands will continue to experience more severe pressure from livestock grazing considering the increasing human population coupled with increased demand for livestock products (Bardgett et al., 2021). Therefore, understanding the impacts posed by livestock grazing in rangelands is essential in order to develop an effective strategy of managing the rangelands that will balance its conservation for economic benefit.

In addition, exploring the integrity of rangelands is a daunting task because both above-ground and underground vegetation performance has to be assessed. Remote sensing provides an opportunity to explore the integrity of a given landscape. For example, satellite remote sensing is commonly used to detect and map LULCC and land degradation due to its repetitive data acquisition (Hu et al., 2019). The South African land cover mapping programme GIS Data Downloads | EGIS (environment.gov.za). Dynamics in land cover have serious implications on rangeland integrity. For example, a reduction in grassland cover may impair grazing capacity, thus influencing livestock production. Therefore, linking land cover changes to rangeland production is crucial. Consequently, analysis of dynamics in land cover change could be the starting point for understanding rangeland integrity since land cover changes may signify degradation. Land degradation is a process in which the value of the biophysical environment is negatively influenced by a variety of human-induced processes that act on the land (Palmer & Bennett, 2013). According to Barbut and Alexander (2016), land degradation is commonly understood to be the loss or deterioration of biological or economic productivity. However, this loss in rural areas tends to impact more on resource-based livelihoods as many of people’s livelihoods in communal areas are supported by rangelands (Hobbs et al., 2008). Livelihood is often described as a means of obtaining life’s essentials such as food, shelter, medicine, and fodder. Livestock farming as a livelihood in communal rangelands is regarded as the most compelling contributor to land degradation (Ebhuoma et al., 2022). This is caused by extremely high livestock density in communal rangelands, resulting in extensive grazing (Maphanga et al., 2022). For example, Herrero et al. (2009) indicated that livestock as the world's biggest land-use system occupies 45% of the global land area, and estimated that 10% to 20% of rangelands have been heavily degraded.

Assessing land degradation neutrality relies on evaluating long-term time series of remotely sensed vegetation indices. Among these indices, the Normalised Difference Vegetation Index (NDVI) is widely used and recognised as the most common (Baskan et al., 2017). Research has shown a strong correlation between NDVI and land productivity, and therefore the NDVI is commonly used as a proxy for monitoring land productivity (UNCCD, 2017). Monitoring land degradation through productivity change aligns closely with the principles of ecosystem resilience theory (Chotte et al., 2019). An essential notion within this context is the agroecosystem's resilience to withstand and recover from disturbance and stress resulting from LULCC. Therefore, understanding the relationship between land productivity and LULCC is crucial for effectively monitoring land degradation and implementing sustainable land management practices.

Related to land cover change, landscape pattern structure is also critical in understanding landscape integrity. The landscape structure is a function of its composition and configuration (McGarigal & Marks, 1994). Landscape structure is critical in determining the extent of fragmentation in a given landscape, which may indicate degradation. Landscape composition encompasses the variety and abundance of patch types within a landscape, but not the placement or location of patches within the landscape mosaic. On the other hand, landscape configuration relates to the physical distribution or spatial character of patches within the landscape (McGarigal & Marks, 1994). For example, landscape configuration may include patch isolation or patch contagion, which are measures of the placement of patch types relative to other patch types, the landscape boundary, or other features of interest. Therefore, applying metrics to describe land consolidation or fragmentation may be critical in rangelands' integrity.

Because of a paucity of information required for input into some land productivity models, earth observation is vital to upscale point-to-area observations. Remote sensing methods of landscape productivity determination are premised on the relationship between net primary production and absorbed photosynthetically active radiation (Gower et al., 1999). It has been established that the NPP of well-watered and fertilised annual crop plants is linearly related to the amount of solar energy they absorbed (Gower et al., 1999; Running et al., 2004) and photosynthetic fixation of carbon by leaves is proportional to absorbed visible radiation. Absorbed Photosynthetically Active Radiation (APAR) depends on the geographic and seasonal variability of day length and potential incident radiation, as modified by cloud cover and aerosols, and on the amount and geometry of displayed leaf material (Running et al., 2004, 1999). This approach has proved to be more robust than direct measures of productivity, which often provide point samples and are destructive. Consequently, light use efficiency (LUE) remains a viable approach and a number of studies based on the LUE model have been conducted (Running et al., 2004; Zhao et al., 2005, 2006, Zhao & Running, 2010; Potter, Klooster, & Genovese, 2012) based on such algorithms.

Related to light efficiency, the development of vegetation indices to monitor vegetation phenology has been key to rangeland monitoring (Parplies et al., 2016; Dube et al., 2021; Matongera et al., 2021; Munyati, 2022a). Such studies also used vegetation indices as a proxy for biomass to estimate rangeland production. While remote sensing has several advantages (Booth & Tueller, 2003) in showing rangeland phenology, research on nutritional status has been lacking. However, recently, some studies have shown the feasibility of applying remote sensing in describing rangeland nutritional status. For example, the nutrient status of rangelands using remote sensing has been described (Dube et al., 2021; Munyati, 2022b; Ramoelo et al., 2015). Nevertheless, these methods may be unable to describe rangelands integrity comprehensively. For example, several uncertainties are associated with the epsilon methods (Zhao et al., 2005; Parplies et al., 2016). Flombaum and Sala (2007) also report that remote sensing techniques of evaluating landscape integrity had challenges related to spectral response by bare soils and that different plant species could have similar spectral signals. Therefore, ground-based methods are still relevant at the plot scale when species or life-form response is necessary as well as for calibrating remote sensing methods. The present study sought to explore the influence of grazing exclusion on rangelands integrity, making ground-based methods relevant.

Although there are studies that have investigated the impact of livestock grazing on plant cover, plant diversity, above and below-ground productivity and its functionality (Altesor et al., 2005; Cingolani et al., 2005; Milchunas et al., 1988; Westoby, 1989), the general effect of livestock grazing exclusion on annual net primary productivity, species diversity and richness in informing the rangeland management strategy has been lacking. For example, the reduction in the dominance of preferred species may result from selective grazing, influencing vegetation cover, plant community structure and biomass (Diaz et al., 2000). In this study, livestock grazing exclusion offers an opportunity to provide evidence on the impact of continuous grazing on the adjacent areas within the same rangeland where evidence in annual net primary productivity and species diversity can be explored to improve the function of the rangeland and support the strategic intervention on rangeland management. Of major interest, this study provides an opportunity to understand the improved rangeland functionality as a driver of ecological and social dynamics across the rangeland system. This is because an improved annual primary productivity when grazing is excluded not only offers improved forage for livestock but also restores the lost diversity, reduces soil erosion and subsequently improves plant water use and carbon storage. In this study we applied remotely sensed data to determine rangelands integrity by evaluating dynamics in land cover, and landscape pattern change and we finally conducted a grazing exclusion experiment. Enclosures were established across the Tsitsa River Catchment to explore the impact of grazing exclusion on continuously grazed rangelands. Finally, we collected soil samples inside and outside exclosures to determine variations in soil characteristics attributable to grazing exclusion. In this study, we used two parallel lines of evidence, including remote sensing and ground-based rangelands assessment, to describe rangelands' integrity.

3.2 MATERIALS AND METHODS

3.2.1 Land use land cover maps

We accessed the South Africa land cover map from the Department of Environmental Affairs website (GIS Data Downloads | EGIS (environment.gov.za). We then clipped catchment T35A and reclassified national land cover classes to be relevant to the catchment (Table 3.1). We used data from 1990, and 2014 generated from the Landsat satellite at a spatial resolution of 30 and the 2018 and 2020 maps generated from Sentinel 2 images at a spatial resolution of 20m. Subsequently, we resampled the 2018 and 2020 maps into the 30 m resolution of previous national land cover maps. Resampling into a lower rather than higher resolution map helped to reduce false accuracy. According to the South African land cover map programme, overall accuracy for the 1990 map was not assessed because no suitable historical reference data was available. However, results from this mapping are believed to be accurate given that similar procedures were followed in producing the 2014 map that had an overall accuracy of 82.53%. On the other hand, the 2018 and 2020 maps had overall accuracies of 91.32% and 85.47% respectively GIS Data Downloads | EGIS (environment.gov.za). We then computed areas covered by each land cover type in hectares.

Table 3.1. Adaptation of the national land cover classes to the catchment land cover types

National land cover class	Adapted land cover class
Degraded Unimproved (natural) Grassland Unimproved (natural) Grassland Shrubland and Low Fynbos	Grassland
Forest (indigenous) Thicket, Bushland, Bush Clumps, High Fynbos	Forest
Bare Rock and Soil (natural) Bare Rock/Soil	Bare ground
Cultivated, permanent, commercial, irrigated Cultivated, temporary, commercial, dryland Cultivated, temporary, subsistence, dryland	Cultivation
Forest Plantations (clear felled) Forest Plantations (Other/mixed spp.) Forest Plantations (Pine spp.)	Plantations
Urban/Built-up (residential, formal township) Built-up Mines and Quarries (surface-based mining) Mines and Quarries	Settlements
Waterbodies	Waterbodies
Wetlands	Wetlands
Fallow	Fallow

3.2.2 Land use transition matrix

Maps were compared with successive image series to quantify the dynamics of land use/land cover and analyse changes over time. This method is used to describe the extent of conversion of different land uses over different periods (Hu et al., 2019). We used the SCP plugin in QGIS version 3.3 software to create the area's cross-tabulation matrix (transition matrix). The transition matrix provides a comprehensive overview of the changes in land use. The details of the transition approach of the study are described by Zhang et al. (2017). The land use transition matrix was used to calculate the changes in land use types for different periods, including 1990-2014, 2014-2018 and 2018-2020. The transition matrix showed the extent of unchanged land use types and conversions during the study periods. Land use gains and losses were determined based on the matrix. A gain in a land use type indicated an increase in its area between the study periods, while a loss indicated a decrease in that land use type (Biondini & Kandus, 2006). Specifically, gains referred to the conversion of other land use types to the specified type, while losses referred to the conversion of the specified type to other land use types.

3.2.3 Landscape pattern changes analysis.

Landscape metrics related to landscape composition and configuration were calculated in Fragstats v4.2.1.603 (McGarigal & Marks, 1994) at patch, class and landscape levels. Landscape metrics at both class and landscapes level were subjected to principal components analysis to reduce data dimensionality and multi-collinearity (Cushman et al., 2008). At landscape level, the largest patch index, (LPI), edge density (ED) and Shannon diversity index (SHDI) explained the highest variation, while at class level, the percentage land (PLAND), ED and LPI accounted for higher variation. At patch level, gyrate explained most of the variation. Consequently, we eliminated other metrics from further analysis.

3.2.4 Land degradation data

We accessed the global land productivity dynamics map (Cui & Li, 2022) and clipped the study area. We computed the 2016 map as a baseline and the 2022 map of the study area to compare changes in degradation trajectories. These maps show landscape degradation status by indicating areas of declining productivity, early signs of decline, stable but stressed, stable and increasing productivity.

3.2.5 Annual standing grass biomass

A total of nine enclosures of 4 square meters were established throughout the Catchment during June 2022. The enclosures were established to exclude livestock grazing in the selected sites in order to explore the annual rangeland productivity without grazing. Disk pasture meter was used to measure annual grass standing biomass inside and outside the enclosures following Bransby and Tainton (1977). A total number of nine points of the height of the standing biomass were randomly taken inside the enclosures, while four points of the standing biomass were randomly taken immediately outside the enclosures. Once the standing biomass from DPM readings were recorded, the grass standing biomass was harvested inside the enclosures. The same procedure was followed in areas immediately adjacent to the enclosures. Once the standing biomass was harvested, the dead materials were removed from the sample, and grass biomass was placed in brown paper bags. The harvested grass sample was oven-dried for 72 hours at 60 degrees Celsius and weighed to calculate the annual grass dry biomass. Based on the relationship between the DPM settling height and dry matter grass weight per point, dry matter production was estimated throughout the catchment.

3.2.6 Soil data

Soil samples were collected in the same sampling points (inside and outside the enclosures) where vegetation composition was recorded. At each sampling point, a soil auger was used to collect soil up to a 20 cm depth. The samples were sent to the Soil Analytical Services Laboratory at Dohne Agricultural Development Institute in Stutterheim, South Africa and analysed for organic carbon, P, K, N, Mg, Ca, Zn, acid saturation, CEC, Mg, bulk density, pH and total cations. The analysis followed the AgriLaboratory Association of Southern Africa Handbook guidelines (AgriLASA Soil Handbook, 2004). These variables were selected because they are critical indicators of soil status. We applied the non-parametric Mann-Whitney U test to test if the distribution of each soil variable was the same across the categories of site (inside or outside exclosures).

3.3 RESULTS

Grassland was the dominant (>68%) land cover type in the catchment (Figure 3). The forest cover type declined by 3.3% while the plantation cover type increased by 8.9% in the catchment between 1990 and 2020. Grasslands declined by 3.8%. By 2018, the Fallow land cover type began to emerge in the catchment (Figure 3).

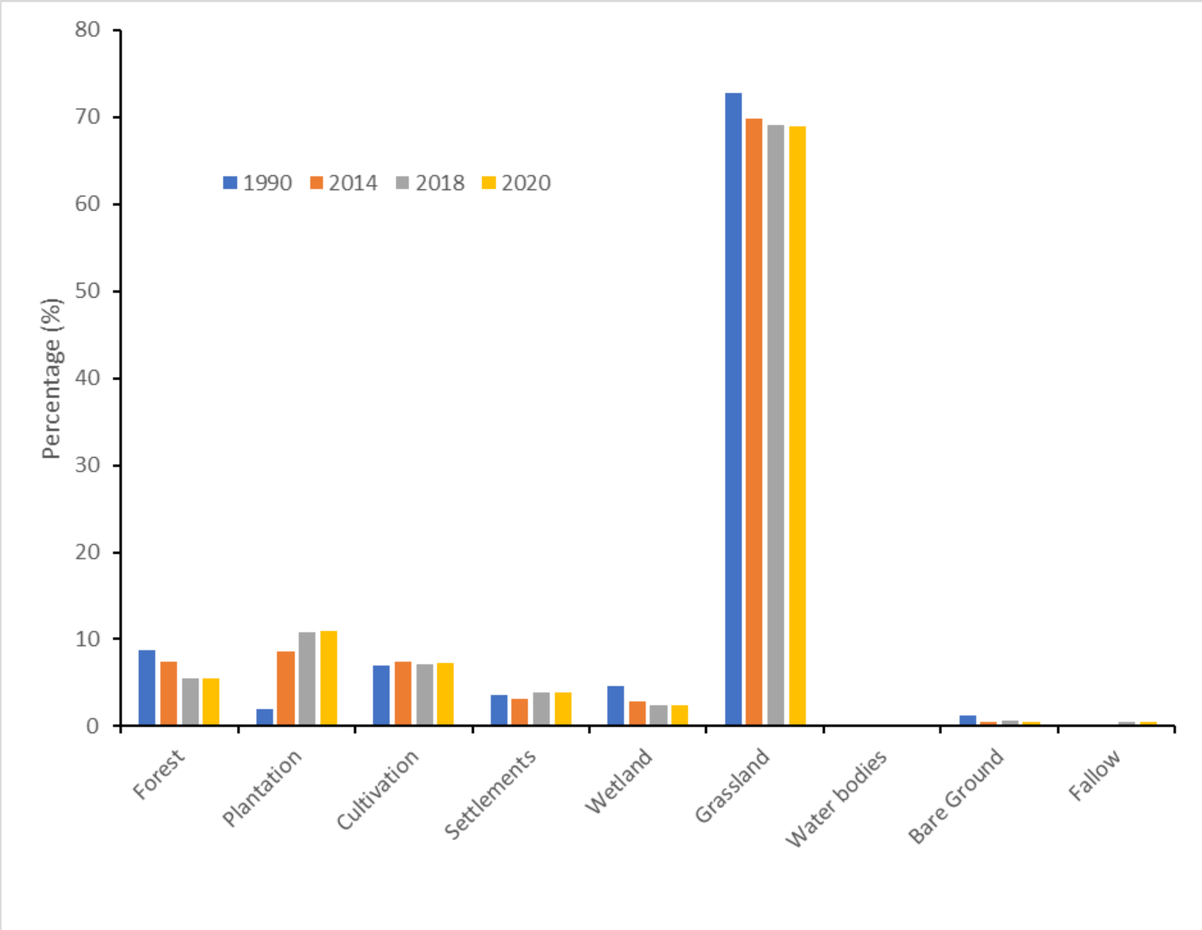

Figure 3.1. Time series vegetation conversion in the study site

Between 1990 and 2020, most of the Grassland cover type was converted to Plantations and Forests. This trend continued into 2018. However, a big portion of the Forest cover type was also converted to grassland and bareground in the same period and so was the plantation cover (see Tables 3.2-3.4).

Table 3.2. Land cover type transition matrix (ha) during the period 1990-2014

	Land cover types 2014								
Land cover type in 1990		Forest	Plantation	Cultivation	Settlements	Wetland	Grassland	Water bodies	Bare Ground
	Forest	1352.79	72.54	25.2	3.42	68.94	2934.09	1.08	128.34
	Plantation	57.06	656.82	7.47	0.54	36.63	300.33		
	Cultivation	22.05	2.25	3215.52	7.83	25.74	384.84		3.6
	Settlements	22.5	0.36	30.06	1585.26	4.95	207.27		1.17
	Wetland	174.78	234.99	86.4	1.17	830.43	1119.24	2.16	1.17
	Grassland	2149.11	3512.16	531.9	47.52	546.57	31340.97	3.6	96.12
	Water bodies	0.27	0.09			0.27	0.36		0.09
	Bare Ground	86.22	62.01	35.64	1.71	15.57	414.99	0.09	56.97

Table 3.3. Land cover type transition matrix (ha) during the period 2014-2018

	Land cover types 2018									
Land cover type in 2014		Forest	Plantation	Cultivation	Settlement	Wetlands	Grassland	Water bodies	Bareground	Fallow
	Forest	1389.36	168.24	17.8	24.56	18.72	2426.44	3.8	39.68	3.68
	Plantation	1.04	4575.36	2.4	0.84	8.88	199.64	0.52	2.12	5.68
	Plantation	1.04	4575.36	2.4	0.84	8.88	199.64	0.52	2.12	5.68
	Settlements	16.2	0.08	22.24	1692.28	0.96	7.8	0.2	0.12	
	Wetland	42.16	40.44	28.76	50.48	1130.04	296.16	18.56	5.84	9.16
	Grassland	1298.92	1198.12	301.44	310.32	197.2	34934.2	13.32	279.48	259.24
	Water bodies	0.04	0.12		0.24	0.96	4.28	1.52	0.04	
	Bare Ground	24.64	0.04	2.76	3.72	0.8	228.04	0.52	41.08	0.48

Table 3.4. Land cover type transition matrix (ha) during the period 2018-2020

	Land cover types 2020									
Land cover types 2018		Forest	Plantation	Grassland	Water body	Wetland	Bare ground	Cultivation	Fallow	Settlement
	Forest	2374.84	9.96	407.88	0.48	1.44	1.4	5.28		22.8
	Plantation		5838.48	114.56	0.44	9.24	6.96	0.36	13.96	1.76
	Grassland	645.8	169.04	37624	1.88		34.84	66.68		1.16
	Water bodies	1.48	0.52	5.12	21.8		1.72	2.32	0.16	1.12
	Wetland	0.64	11.72	0.04	2.24	7.28		0.44		0.08
	Bare-ground	1.68	0.8	156.8	2.04	1348.24	211.8	0.68	0.16	30.68
	Cultivation				0.12			3979.32		
	Fallow		11.24		0.04		0.04	0.48	267.32	0.04
	Settlements	10.64	1.68	4.32	0.16	0.24		1.28	0.32	2108.16

3.3.1 Landscape pattern change

At the landscape level, both the largest patch index and edge density declined while the Shanon Diversity Index (SHDI) slightly increased during the study period.

Table 3.5. Landscape level metrics at the landscape level

Year	LPI (%)	ED (m ha ^{2})	SHDI
1990	71.48	95.44	1.02
2014	67.39	83.95	1.09
2018	64.60	67.11	1.12
2020	64.08	66.38	1.12

NB: LPI – Largest Patch index, ED – Edge Density, SHDI – Shannon Diversity Index

Grassland was the most consolidated land cover type at the land cover class level whilst water bodies were the least common land cover type in the catchment. Edge density was highest with respect to the Grassland land cover and lowest for the Water body cover type (Table 3.6).

Table 3.6. Average landscape metrics at class level at the catchment (1990-2023)

Year		PLAND (%)	LPI (%)	ED (m ha^{-2})
1990	Grassland	72.85	71.48	86.95
	Forest	8.72	0.30	50.57
	Bare Ground	1.28	0.03	10.55
	Wetland	4.66	0.48	20.20
	Plantation	2.0132	0.90	8.78
	Water bodies	0.0023	0.0007	0.03
	Fallow Land	3.5367	0.468	3.4833
	Cultivation	6.9501	0.9804	10.3098
2014	Grassland	69.9384	67.3902	77.7851
	Forest	7.3536	0.351	43.3827
	Bare Ground	0.544	0.0193	3.8866
	Wetland	2.9041	0.2733	12.7101
	Plantation	8.6379	1.5314	15.1572
	Water bodies	0.0137	0.0019	0.1253
	Settlements	3.1437	0.4375	3.4437
	Cultivation	7.4646	1.0611	11.41
2018	Grassland	69.43	64.60	60.54
	Forest	5.0924	0.4779	23.0502
	Bare Ground	0.6689	0.0102	6.4547
	Wetlands	2.4486	0.1546	9.7958
	Plantation	10.769	1.8194	16.2042
	Water bodies	0.0756	0.0135	0.6988
	Settlement	3.8247	0.4739	5.636
	Cultivation	7.1872	0.8272	10.2219
	Fallow Land	0.5006	0.167	1.6149
2020	Grassland	68.9592	64.0798	60.2952
	Forest	5.4819	0.5094	23.9232
	Bare Ground	0.4648	0.0058	4.6726
	Wetlands	2.4573	0.1551	9.7846
	Plantation	10.8941	1.8986	16.2714
	Water bodies	0.0509	0.0021	0.5472
	Settlement	3.9022	0.4807	5.5093
	Cultivation	7.2912	0.8438	10.1509
	Fallow Land	0.4983	0.1625	1.6039

NB: PLAND – Percentage Land, LPI – Largest Patch index, ED – Edge density

3.3.2 Patch level dynamics in landscape configuration

The distance between patches was greatest in settlements before 2014, while the distance between bare patches progressively increased and between grass patches decreased. The distance between plantations land cover type was also increasing while the distance between cultivation land cover type decreased. Wetlands and water bodies were also becoming dispersed in the catchment.

Table 3.7. Dynamics in landscape configuration (1990-2020)

	GYRATE (m)			
Land cover type	1990	2014	2018	2020
Grassland	37.68054	45.12095	19.41506	18.99827
Forest	26.95634	27.18504	29.42467	28.15525
Bare Ground	21.54207	23.75192	54.42019	64.16472
Wetland	40.64116	43.46874	62.78748	62.188
Plantation	25.89624	72.34612	86.79197	82.25084
Water bodies	15.69649	20.86083	151.2123	165.4157
Settlements	210.5615	200.2132	18.51018	17.88122
Cultivation	141.0361	134.2705	43.72324	45.67257
Fallow land			56.41826	56.06837

3.3.3 Land productivity dynamics

Concerning land productivity dynamics, only 2% of the catchment was classified as declining in productivity, whilst 77% was classified as stable in 2022 (Table 3.8) and (Figure 3.2).

Table 3.8. Land productivity dynamics at Tsitsa catchment (2016-2022)

Land productivity dynamics	2016 (%)	2022 (%)
Declining productivity	5.155335	2.014405
Early signs of decline	41.49032	2.216971
Stable but stressed	0.787933	1.406707
Stable	45.31742	77.36889
Increasing	7.248987	16.99302

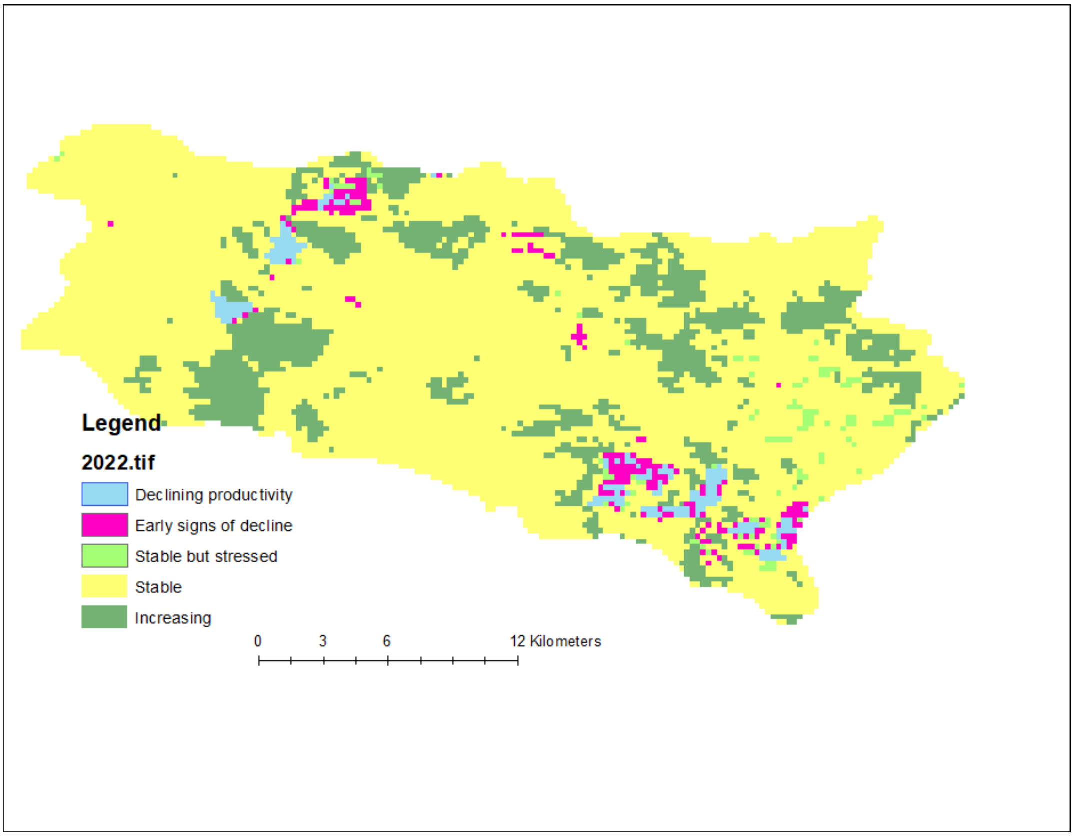

Figure 3.2. Land productivity dynamics (2016-2022

3.3.4 Land productivity transition matrix

The largest part of the catchment was transitioning to a stable condition in terms of land productivity.

Table 3.9. Land productivity transition matrix

	Declining productivity (%)	Early signs of decline (%)	Stable But stressed(%)	Stable (%)	Increasing(%)
Declining productivity	-	6.25	125	2543.75	187.5
Early signs of decline	256.25	175	393.75	20743.75	1468.75
Stable but stressed	50	18.75	18.75	256.25	93.75
Stable	475	568.75	118.75	18493.75	5518.75
Increasing	337.5	462.5	125	931.25	2168.75

3.3.5 Grassland dry matter production in exclosures

Grassland production in exclosures was highly variable, ranging from 111 to 330 gm^{-2} (Figure 3.3). Following the calibration of a disc pasture meter (Figure 3.3), we found an average predicted grass dry matter production of 198 gm^{-2} in the catchment.

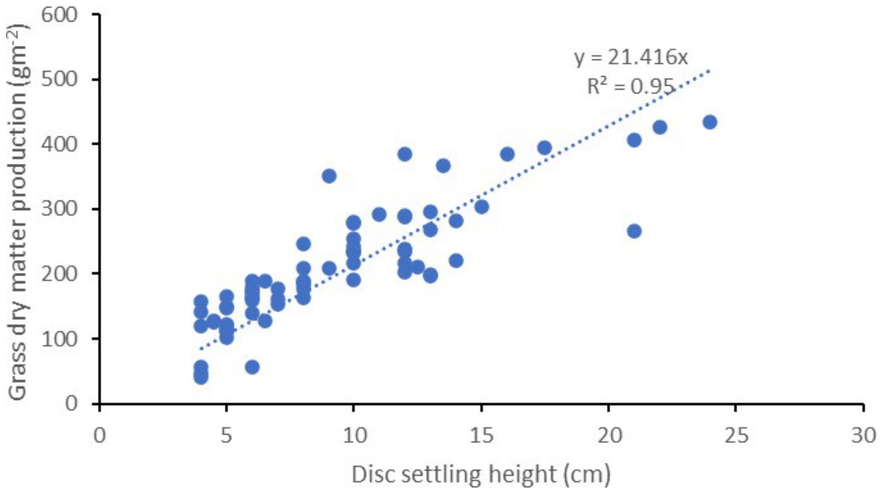

Figure 3.3. Grassland dry matter production in exclosures

3.3.6 Soil variables inside and outside enclosures

There was no significant difference ($p > 0.05$) in soil variables between the inside and outside of exclosures.

3.4 DISCUSSION

3.4.1 Land cover changes

Although grassland cover was the largest land cover type, the progressive decline in its cover suggests that potential land for grazing is also diminishing. This suggests that other land uses need to be judiciously regulated to promote grazing resource production to support livestock. In this regard, there is a need to regulate plantation development, forest expansion and conversion of grasslands into bare ground. These land uses are the main drivers of potential grazing capacity loss in the catchment. From our observations, the increase in forest cover is largely linked to the expansion of invasive alien plants, particularly Australian acacias. This means that although the Working for Water programme is clearing invasive alien plants, the progress is slow. This is consistent with results from other parts of South Africa, for example, Beater et al. (2008) and Mcconnachie et al. (2012).

3.4.2 Land degradation in the catchment

The observed land cover conversions in the catchment are symptomatic of degradation. For example, natural grasslands in the area have been converted to other land uses, thus lowering the potential for this land cover type to offer requisite ecosystem services for the grazier. The landscape pattern analysis also revealed that fragmentation was taking place in the catchment. For example, there was a progressive decline in the percentage of land and a slight increase in patch diversity. Settlements and grasslands were becoming more clustered as the gyrate metric declined while plantations were becoming dispersed. However, the land productivity dynamics product suggests improvement in the catchment in terms of productivity. Although this might be true, we argue that this is symptomatic of the degradation of the grassland biome as it is being replaced by highly productive cover types such as Plantation and Forest. This kind of productivity may not benefit livestock farmers in this catchment. In this regard, ground-based methods will be critical to better understand catchment degradation. As a result, we set up grazing exclosures and evaluated soil quality to monitor production and soil quality potential over time.

3.4.3 Grass dry matter production

Following a full season of grazing exclusion in 8 exclosures across the catchment area, we found grass dry matter production of 198 gm^{-2} in the catchment. This was lower than production from grazed commercial and communal rangelands reported by O'Connor (2008). It was also lower than figures from communal grazing lands cleared of invasive alien plants reported by Gwate et al. (2021). This may suggest that the system has been degraded and may need judicious grazing management, including resting to help improve grass production. It is prudent to continue monitoring exclosures to determine improvements in grass production and grassland species richness. We hypothesise that more species are likely to emerge in the exclosures if they are monitored over time, and one season may not provide conclusive data.

3.4.4 Influence of grazing exclusion on soil properties

With respect to soils, we did not find any statistically significant differences between soils from the inside and outside of exclosures. Additional seasons of soil monitoring will be required to determine the influence of grazing exclosure on soil properties. We note that physical and chemical soil characteristics influence grass production and nutrient recycling (Costantini et al., 2016). Resources permitting, soil quality could be reassessed after 3 or 4 seasons to decipher any changes.

3.4.5 Conclusion

The study sought to determine rangeland integrity in the Tsitsa catchment. Remote sensing confirmed that the catchment was fragmenting, suggesting that degradation was taking place. The reduction in grassland cover type is likely to undermine rangeland production, and this could have serious implications for livestock production in the catchment. We found that after one season of grazing exclusion, soil properties did not differ from those exposed to open grazing. Therefore, in order to enjoy the full benefits of grazing exclusion, several seasons will be required to monitor the response of soil variables. This could provide useful information regarding the potential for autogenic recovery for these grasslands. Grass dry matter production was relatively low, an indication of long-term degradation that took place in these communal rangelands. Remote sensing on its own may be unable to adequately evaluate rangelands integrity. Consequently, combining remotely sensed and ground-based data in rangelands evaluation is vital to achieve the elusive goal of sustainable rangelands management.

CHAPTER 4 A SWAT+ WATER BALANCE ASSESSMENT FOR THE T35A QUATERNARY CATCHMENT, EASTERN CAPE

4.1 INTRODUCTION

Land degradation is a significant issue in South Africa, affecting about 70% of the country's surface due to varying intensities and types of soil erosion (Le Roux, 2007). Approximately, 60% of the land is degraded, with 91% prone to desertification (Mani et al., 2021). Human activities, such as vegetation clearing and overgrazing accelerate soil erosion, particularly in the Eastern Cape province, where poor farming practices and land abandonment exacerbate the problem (Le Roux, 2007). Woody encroachment intensifies land degradation, driven by climate change, historical land tenure policies (Mani et al., 2021), and the spread of alien invasive species. Both communal and commercial lands face land degradation due to woody plant encroachment (Odindi, 2023).

Understanding the impact of land use and land cover (LULC) change on soil loss is vital for sustainable land management. Globally, studies reveal that cultivated and bare land generate the highest erosion rates (Alkharabsheh et al., 2013; Aneseyee et al., 2020; Fu et al., 2021), emphasising the seriousness of land degradation in the Tsitsa catchment dominated by agriculture. Addressing soil erosion is crucial due to its impact on fertility, slope instability, ecological deterioration, low agricultural production, and poverty (Aneseyee et al., 2020; Fu et al., 2021).

Research also demonstrates the significant impact of LULC change on hydrology. Pasture land dominance increases surface runoff and sediment yield (Afonso de Oliveira Serrão et al., 2022). A decrease in grassland and shrubland, coupled with increased agriculture and urbanisation, leads to increased surface runoff and decreased groundwater flow (Getu Engida et al., 2021). Cultivated land expansion results in increased surface runoff, reduced groundwater contribution, and altered water yield (Mutayoba et al., 2018). Afforestation reduces water yield and surface runoff while enhancing evapotranspiration (Saddique et al., 2020).

Hydrological modelling studies have been conducted in the Tsitsa River Catchment, but much research has focused on the impact of LULC on water balance. However, knowing the relationship between hydrology and vegetation is vital for this rangeland management project. Therefore, this assessment will apply the SWAT hydrological model to explore the impact of land cover on hydrological water balance in the study areas. Additionally, the hydrological assessment will consider the scenarios of alien vegetation (black wattle) invasion. The trade-off between the wattle, hydrology, erosion and sediment yield will be explored. The outcomes contribute to outlining rangeland management approaches by ensuring that management activities such as alien vegetation clearing do not result in negative feedback on environmental and ecosystem services.

4.2 METHODS AND MATERIALS

4.2.1 Site description

The T35A Quaternary catchment is a sub-catchment of the Tsitsa River Catchment located in the Eastern Cape province of South Africa (Figure 4.1). The region is characterised by cold, dry winters and warm wet summers. The mean annual precipitation of the catchment ranges between 625mm and 1327mm in low plains and mountains, respectively (Le Roux & Van der Waal, 2020). The warmest and most wet month is January, and the coldest and driest month is July (Huchzermeyer et al., 2019). Temperatures are warm, with daily mean summer temperatures of 12°C to 26°C and daily mean winter temperatures of 4°C to 18°C (Theron et al., 2021).

The catchment's soils, mainly duplex, are highly erosive and dispersive (Theron et al., 2021). Clayey or loamy soils with variations in texture and soil depths ranging from 10 cm to 200 cm dominate the areas. Flatter terrain, such as lower foot slopes and valley bottoms, exhibit soil depths of ~50cm (Theron et al., 2021). The soils vary significantly, with the central parts characterised by mudstone parental material and some parts dominated by sandstones (van Tol et al., 2016). Mudstones in the catchment are associated with high erosion (Le Roux & Van der Waal, 2020), evident in gullies, primarily in low-lying areas near settlements and linked to grassland degradation (Itzkin et al., 2021).

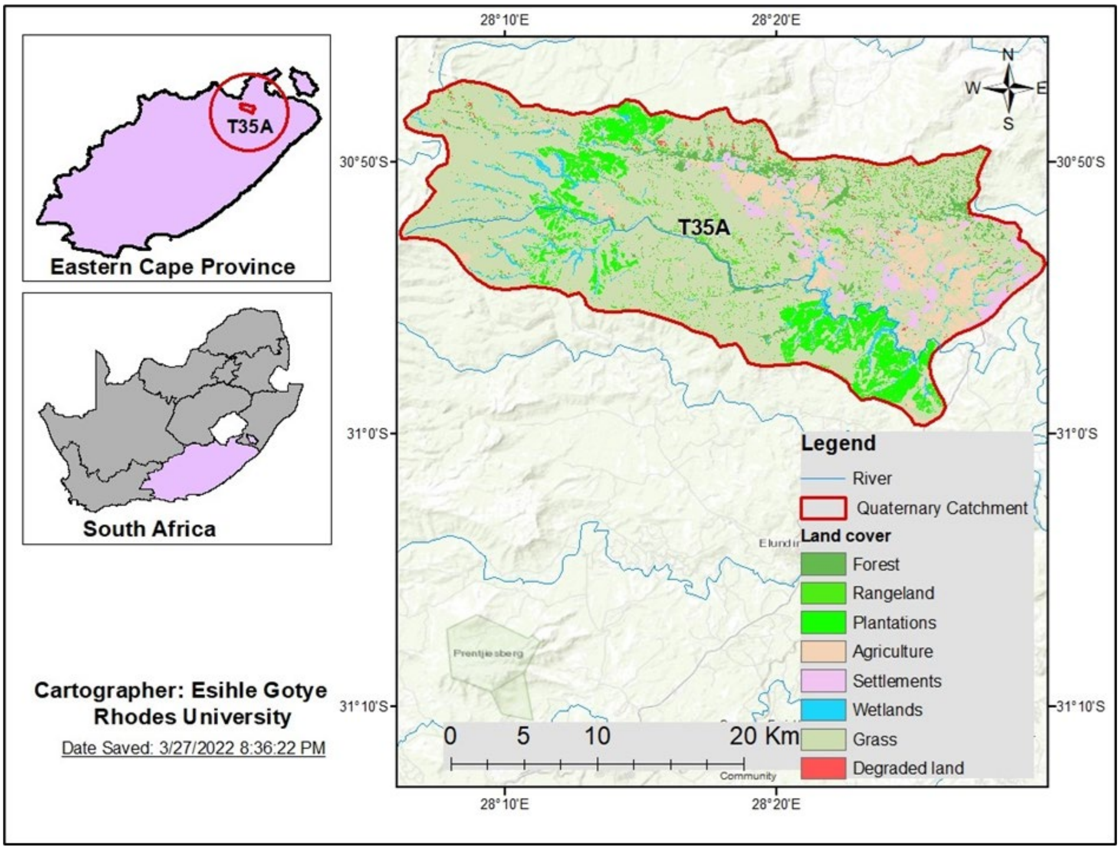

Figure 4.1. Location of the study area in South Africa. The T35A quaternary catchment is a sub-catchment of the Tsitsa River catchment.

Natural vegetation, the predominant land cover (72%), includes grassland/rangeland (90%), thicket (6.9%), forest (3%), and shrubland (0.1%) (Theron et al., 2021). About 15% comprises cultivated commercial and subsistence agriculture, with extensive livestock grazing in grassland areas. The remaining 13% includes plantations, towns, forests, and water bodies (Theron et al., 2021). Rural settlements are mainly in the middle and lower parts, where gully erosion is prevalent (Itzkin et al., 2021). Communities engage primarily in subsistence crop and livestock farming, with land allocated by traditional authorities (Van Tol et al., 2016). Primary land uses involve extensive grazing, primarily for cattle on high-lying land (Van Tol et al., 2016). Subsistence farmers are affected by land degradation, particularly due to mismanaged, unsustainable, and extensive overgrazing, a primary cause of degradation, mainly in low-lying areas (Van Tol et al., 2016).

4.2.2 SWAT model data inputs

The Soil and Water Assessment Tool (QSWAT+) version is applied in this assessment. A wide range of input data is required by the SWAT, including the digital elevation model (DEM), land cover data, soil and climatic data. A DEM at 30 m resolution was used to delineate the topographic features of the catchment, including the slope, stream network and the catchment outlet. The DEM was obtained from the United States Geological Survey (USGS) Earth Explorer (https://earthexplorer.usgs.gov/ Accessed:08/04/2022) and processed using ArcGIS 10.8 version (Figure 3.2). The Department of Forestry, Fisheries, and the Environment obtained a land cover map of the study area. The map contained eight land cover classes: barren land, built-up, cultivated, forested land, grassland, mines and quarries, waterbodies, and wetlands (see Figure 4.2).

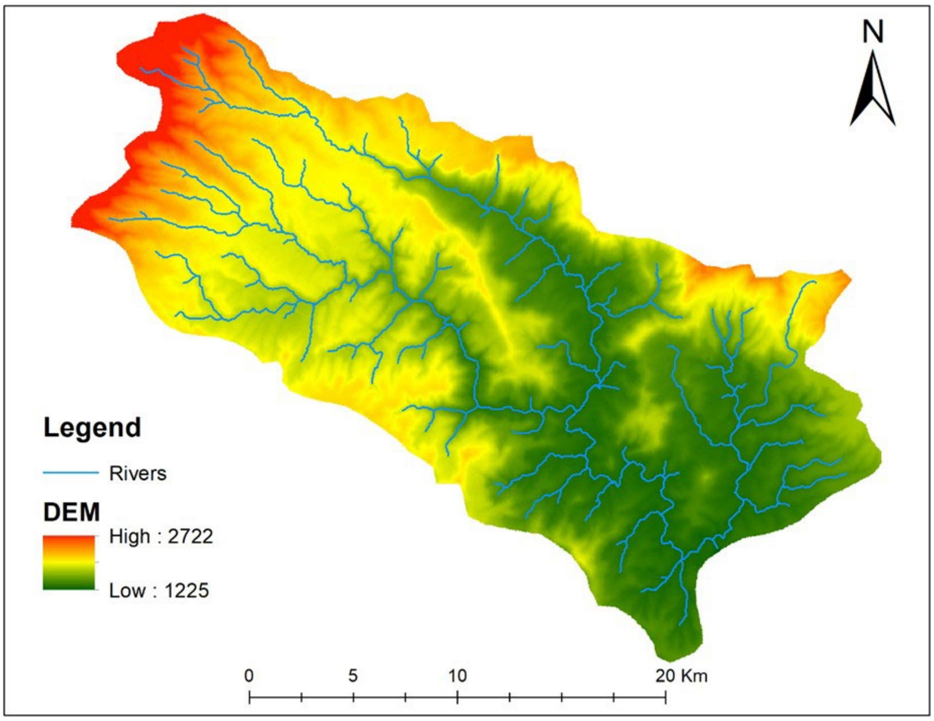

Figure 4.2. A DEM map showing the topography of the study (T35A).

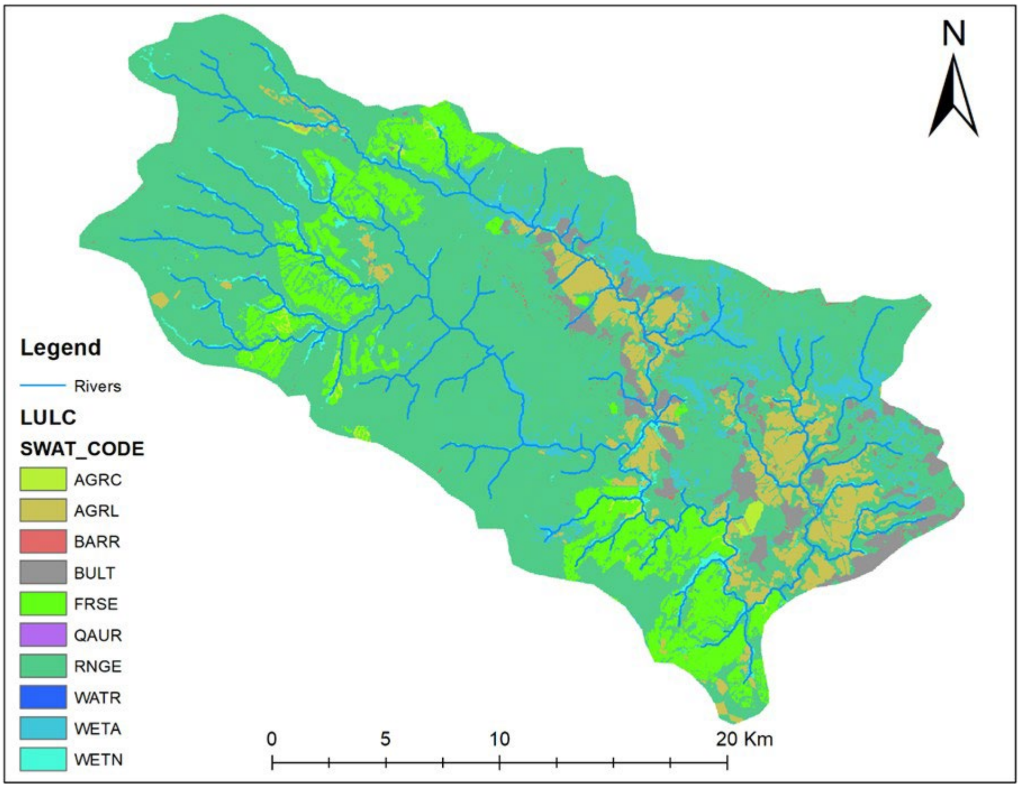

Figure 4.3. The land cover map of the T35A quaternary catchment

The soil map data were obtained from the Food and Agriculture Organization (FAO), and the soil properties of the study area were defined using the World Harmonised Soil Database (Figure 3.4). Five soil classes were identified, including Haplic Acrisols (Ach), Rhodic Ferrasols (FRro), Eutric Regosols (RGe), Ferric Luvisols (LVfi), and Gelic Leptosols (LPli). Additional soil attributes were sourced from the le Roux et al. (2022) database. SWAT requires daily weather data, including temperatures, precipitation, relative humidity, solar radiation, and wind speed. Due to a lack of data, only observed long-term precipitation and limited temperature data were used in this study. The SWAT weather generator obtained the weather variables (precipitation and temperatures). Daily precipitation for the Maclear weather station was obtained from South African Weather Services from 1 January 2010 to 31 March 2022, but this station was rather far from the study area. More rainfall data were obtained from the Rhodes University Geography Department for Hlankomo and Tsitsana stations measured from 2015 to 2019. Table 4.1 provides a summary of SWAT input sources and resolution.

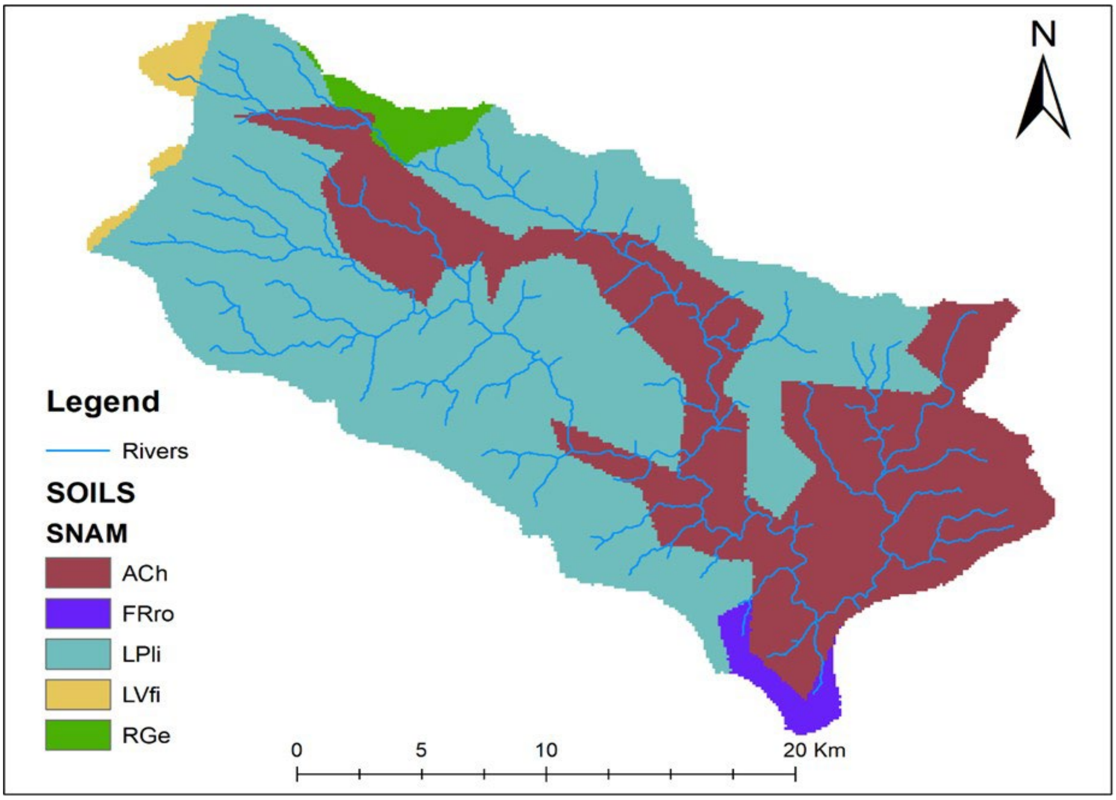

Figure 4.4. A map showing the different soil types in the T35A catchment.

Table 4.1. A summary of SWAT model data inputs and sources.

Data Input	Resolution	Source
Digital Elevation Model (DEM)	30m	USGS Earth Explorer https://earthexplorer.usgs.gov/
2020 National Land Cover map	30m	Department of Forestry, Fisheries, and the Environment (DFFE)
Soil map	30m	Food and Agriculture Organization (FAO) https://www.fao.org/home/en
Climate Data ● Temperature ● Precipitation	Daily	SWAT Global Weather Database ● South African Weather Service (Precipitation) ● Geography Department, Rhodes University (Precipitation)
Observed discharge	Daily	Geography Department, Rhodes University

4.2.3 SWAT model set up

A 30 m DEM was imported into QGIS, and the stream network and catchment outlet were defined. Subsequently, the catchment was delineated into thirteen sub-basins (see Figure 4.5). Following the watershed delineation, hydrological response units (HRUs) were defined based on land use, soil type, and slope data. Land use and soil type maps were loaded as input files and look-up tables containing attribute information. total of 189 HRUs were created.

The next steps were completed on the SWAT+ Editor. The required climate data comprising daily minimum and maximum temperature and daily precipitation were imported into the model. The simulation period was 14 years (2005 to 2019), and a five-year warm-up period was set to stabilise initial conditions.

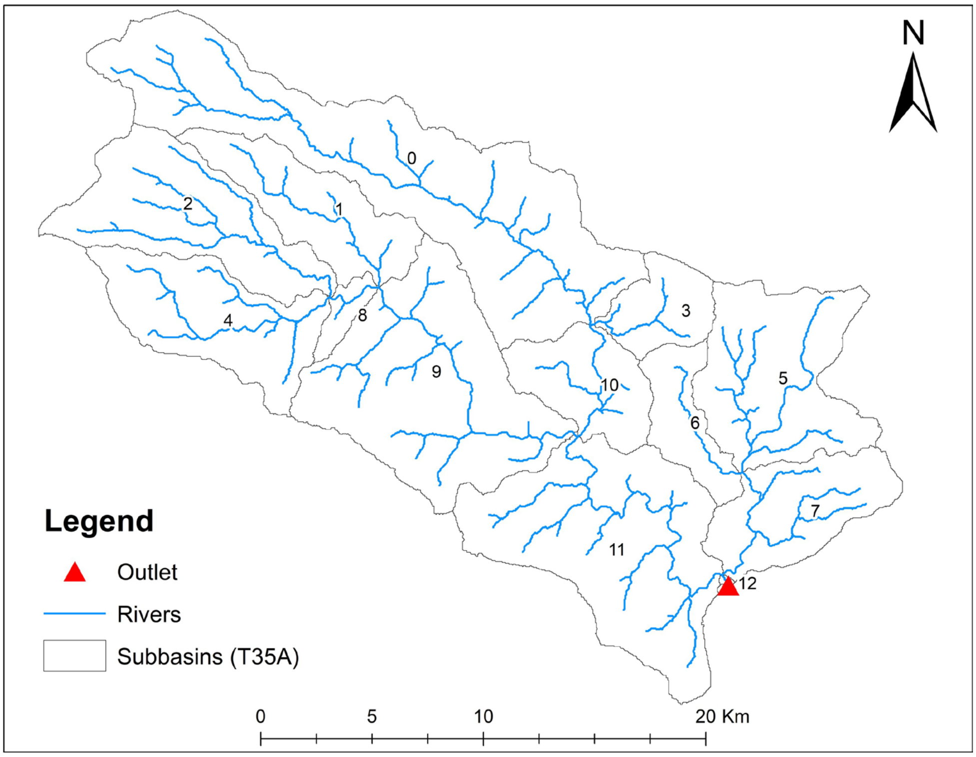

Figure 4.5. A map of the sub-basins in the T35A catchment derived from QSWAT+

4.2.4 Model validation

Daily discharge data measured from 1 December 2015 to 30 May 2019 from Tsitsana were used for calibration. Validation was performed by comparing the output of the SWAT model to the observed data. The model was only validated for streamflow because there was insufficient observed data for sediment. Statistical methods were employed to assess the model's performance during calibration. The Nash and Sutcliffe efficiency (NSE), percent bias (PBIAS), and coefficient of determination (R^2) (Moriasi et al., 2007) were used to check the calibration results' goodness of fit with observed data. Equations 4.1, 4.2, and 4.3 were used to determine the NSE, PBIAS, and R^2." Equations 4.1, 4.2, and 4.3 were used to determine the NSE, PBIAS, and R^2.

Equation 4.1

$$NSE = 1 - \frac{\sum_{i=1}^{n}(O_i - S_i)}{\sum_{i=1}^{n}(O_i - \bar{O})}$$

Equation 1.2

$$R^2 = \frac{[\sum_{i=1}^{n}(O_i - \bar{O})(S_i - \bar{S})]^2}{\sum_{i=1}^{n}(O_i - \bar{O})^2 \times \sum_{i=1}^{n}(S_i - \bar{S})^2}$$

Equation 4.3

$$PBIAS = \left[\frac{\sum_{i=1}^{n}(O_i - S_i) * 100}{\sum_{i}^{n} O_I}\right]$$

where O_i is the observed daily discharge, S_i is the simulated daily discharge, $\bar{O}$ is the average measured discharge, $\bar{S}$ is the average simulated discharge, and n is the number of observations.

4.2.5 Land cover change scenario

Following validation, a scenario of land cover change was explored. The scenario focuses on invasive black wattle and evaluates impacts on hydrology if black wattle invades all the natural land cover in the catchments. To achieve this, natural land cover types were reclassified to wattle in GIS, and a new model set-up was created based on the land cover scenario. All other parameters from the model validation were kept constant. Water balance components such as evapotranspiration (ET), runoff, and recharge water yield were evaluated between the baseline and land cover change scenarios.

4.3 RESULTS

4.3.1 Model performance

The comparison between the observed and simulated flow for model validation for 2016 to 2019 is shown in Figure 4. 6. The model validation was done against observed daily discharge from a gauging station in the catchment, and the resultant performance indicator is shown in Table 4.2. The performance indicators are low but positive. According to Moriasi et al. (2007), the NSE value above zero is a positive model performance, although the standard NSE required for simulations is 0.5. The

SWAT simulation results for streamflow indicate an under-simulation of intermediate flows of some key high flows (see Figure 4.6).

Table 4.2. Model performance statistics.

Catchment	NSE	R^2	PBIAS
Tsitsana	0.67	0.71	-15

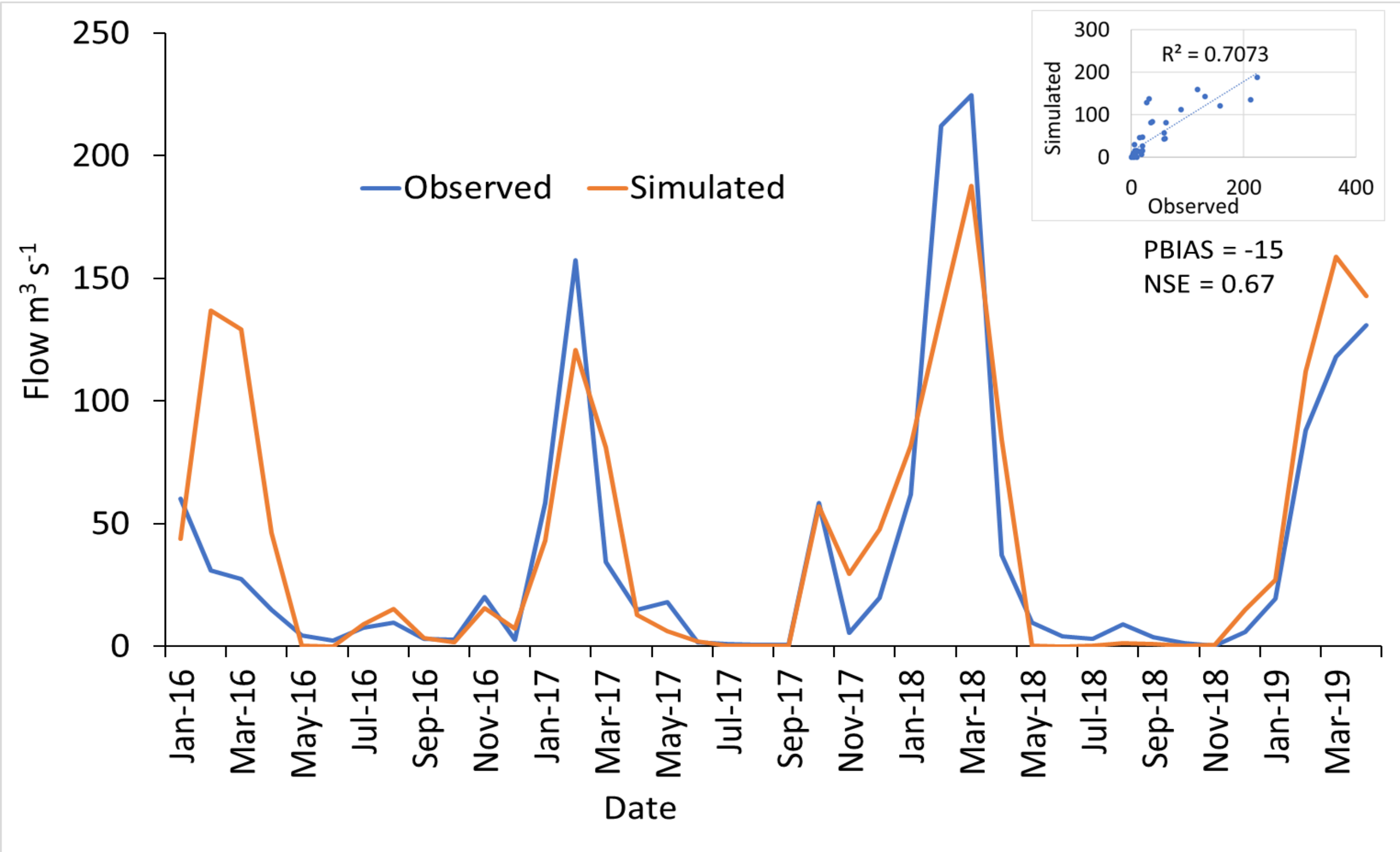

Figure 4.6. Results of the model calibration showing a fair fitting of observed and simulated values for streamflow.

4.3.2 Water balance and landcover

The monthly distribution assessment (see Figure 4.7) indicates that the river flows most of the year. Near zero flows are recorded in June. High streamflow periods are between January and April; flows decline until October.

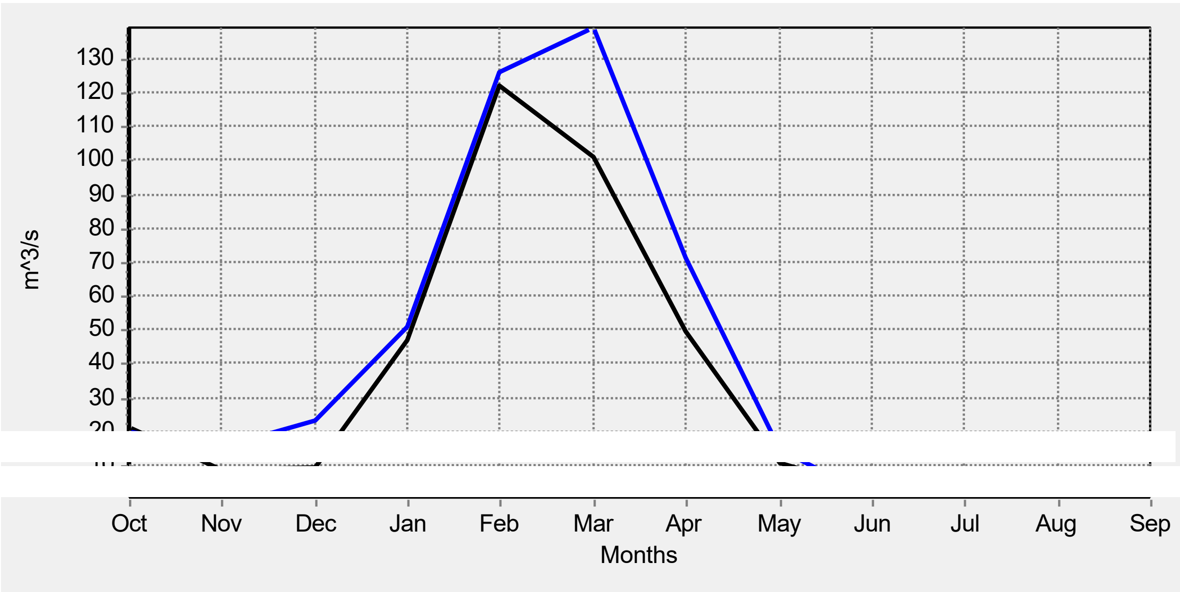

Figure 4.7. Monthly distribution of observed and simulated flows. The black line represents observed values, whereas the blue line represents simulated values.

The water balance ratios in Table 4.3 indicate a high baseflow contribution to streamflow. Nearly 40% of precipitation contributes to streamflow – most of it as baseflow. Percolation is significantly high, aligning with high infiltration and hence baseflow. However, deep recharge is low. Evapotranspiration is very high, taking up ~ 60% of the precipitation.

Table 4.3. Modelled water balance ratios for T35A catchment.

Water Balance Ratios	
Streamflow/Precipitation	0.39
Baseflow/Total Flow	0.78
Surface Runoff/Total Flow	0.22
Percolation/Precipitation	0.38
Deep Recharge/Precipitation	0.02
ET/Precipitation	0.59

Table 4.4 summarises the contributions of the unique land cover and land uses to the water balance at the catchment level. Largely impervious built-up areas cover a small portion of the catchment but contribute most to runoff and sediment generation. Agriculture is the next largest runoff and sediment generator; the land use also exhibits high evapotranspiration levels. The catchment has a high sediment yield of 10.66 Mg/ha^{-1}. Rangeland has moderate evapotranspiration, runoff, and sediment compared to built areas and agriculture. Notably, rangelands produce high amounts of biomass – making them the most productive land cover hydrologically. On the contrary, wattle produces insignificant runoff, low

biomass, and no sediment but has evapotranspiration about 100mm higher than the next water-losing land cover land use type.

Table 4.4. Summary of the partitioning of water balance, sediment yield and biomass in the T35A catchment

LULC	CN	SURQ mm	ET mm	SED t/h	BIOM t/h
Rangeland	56.7	7.2	515.8	0.1	19.5
Forest	51.2	1.8	688.5	0	2.6
Agriculture	69.9	22.8	629.7	0.2	0.04
Wattle	40.5	0	811.9	0	2.6
Built	95.8	521.8	384.4	9.8	0
Wetland	0	0	17.9	0	1.7

At the HRU level, the land cover and land use results are consistent with the catchment level results, but Figure 4.8 gives a temporal distribution of the variation in ET across LULC types. The ET rates peaked in January and October. Relative low values of ET occurred in June, July, and August. ET is highest in wattle, forest, and agriculture. The lowest ET values are from July to September. Table 4.5 summarises specific ET values per land cover land use where wattle is shown to have significantly higher ET than other cover types.

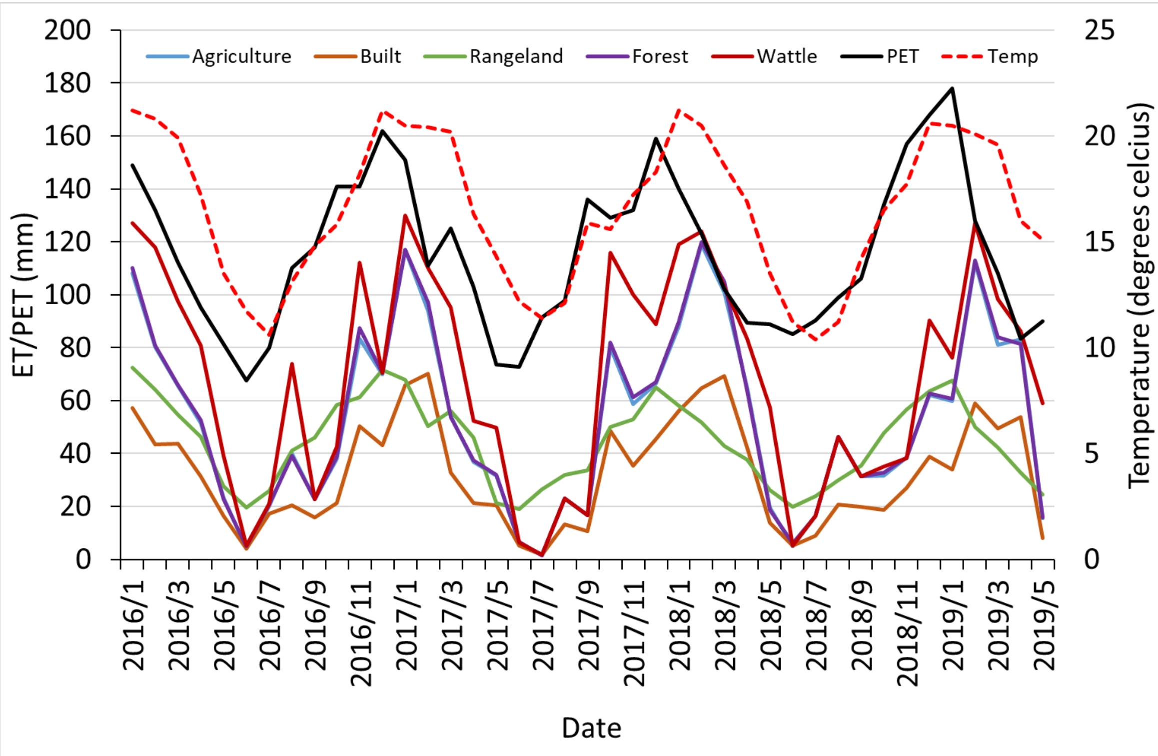

Figure 4.8. The distribution of simulated ET for specific land cover types relative to the PET and temperature.

Table 4.5. Summary of selected ET values for specific land cover types

Agriculture	Built	Forest	Rangeland	Wattle	PET
619.5	378.2	627.6	520.1	798.8	1354.4

4.4 LAND COVER CHANGE SCENARIO

A scenario investigating the impacts of a complete invasion of natural land cover by wattle is presented in Figure 4.9. Generally, the invasion of the catchment by wattle has a large negative impact on water balance components except surface runoff, which showed a slight increase. The impacts are wide-ranging. For example, ET increases by 38%, whereas groundwater reduces by up to 60%. Another positive change from wattle invasion is sediment yield, which reduces by over 40%. Catchment water yield reduces by 22%, meaning that the catchment will lose a fifth of its total water if the wattle completely invades natural land cover types.

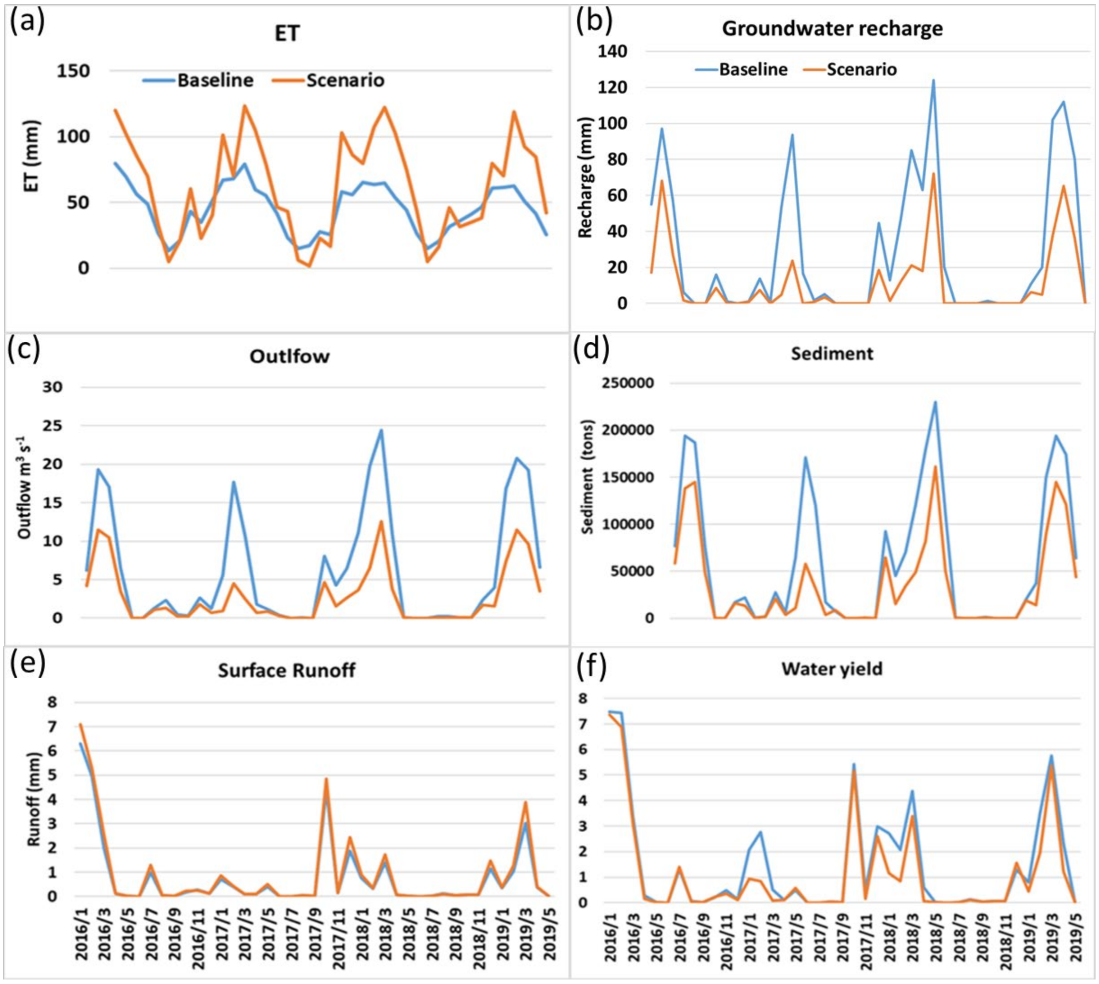

Figure 4.9. An illustration of the differences between the modelled baseline water balance outputs and the same outputs under a scenario of black wattle invasion.

Table 4.6. Summary of the impact of black wattle invasion on water balance and sediment.

Variable	Baseline	Scenario	Change ratio
ET (mm)	45.13	62.35	1.38
Flow out ($m^3 s^{-1}$)	6.11	2.82	0.46
Sediment out (tons)	60446.33	35358.29	0.58
Surface runoff (mm)	0.78	0.91	1.16
Water yield (mm)	1.45	1.14	0.78
Groundwater recharge (mm)	27.85	11.17	0.40

4.5 DISCUSSION AND CONCLUSION

4.5.1 Model performance

The SWAT+ was run at a daily time step, and outputs were aggregated monthly for comparison. The monthly time step is typically the temporal scale at which water resources management is done in South Africa, except when it relates to water quality management (Slaughter et al., 2017). The model performance is good based on the evaluation guidelines provided in the literature. However, significant uncertainties in climate data could have constrained the model from producing the best possible results. Specifically, we did not have temperature data, so global temperature data was used.

Moreover, we used the SWAT+ global weather generator to provide regional information on relative humidity, solar radiation and wind speed. Using such datasets propagate uncertainty; observed datasets are a more reliable option. Unfortunately, we could not access all the observed climate data required by SWAT+. Nevertheless, the available data yielded a good simulation comparable to the observed streamflow; hence, we could confidently perform a water balance and scenario analysis.

4.5.2 Water balance and land cover

The streams in the catchment generally flow throughout the year. The main river has a discharge exceeding 10 $m^3 s^{-1}$ for three-quarters of the year. Only in June is discharge near zero experienced. Baseflow contribution is very high in the catchment and is driven by the soil types synonymous with high silt, sand and rock content. Additionally, hydraulic conductivity is very high, thus enhancing groundwater and lateral flow. During stakeholder workshops, community members reported normally sourcing water from natural springs, indicating the existence of high lateral flow in the catchment. The T35A catchment is generally water-secure – with a river that maintains a healthy flow for most of the year. However, the catchment is a headwater zone whose flow is expected to contribute to the maintenance of downstream ecosystems.

Land cover and land use have been shown to have significant and varied impacts on water balance (Sajikumar & Remya, 2015). Rangeland, which makes up ~70% of the land cover, exhibits moderate impacts on water balance and is the most productive land cover type. This makes a case for protecting rangeland from invasion by land cover types such as wattle with low biomass, near zero runoff and very high-water losses. Areas invaded by wattle require careful management because wattle is bad on water losses and runoff but provides vegetative cover that protects the soil from erosion and sediment transport, similar to natural forest. Programmes of wattle clearance should be accompanied by land rehabilitation to ensure that a productive land cover type, such as rangeland, is established in cleared areas. The general pattern of ET across the different land cover types follows the pattern of the average monthly temperature, and an increase in temperature results in an increase in ET and vice versa. At HRU level, the highest average ET occurred in wattle, natural forest and agriculture. The high ET in wattle is due to invasive alien plants' general greater root depth and growth triggered by temperature and moisture. These results align with those of Dye and Jarmain (2004) that a very high rate of total evaporation is possible in areas with dense black wattle infestation in the riparian zone.

4.5.3 Land cover change scenario

Black wattle invasion is increasing in the T35A and greater Tsitsa Catchment. The scenario explores the impacts of the invasion of water balance. A striking impact of the wattle invasion scenario is the depletion of groundwater recharge. Such a decrease has repercussions on the catchment water supply for household drinking water. Community members highlighted that springs were a preferred and generally safer option for drinking water as they do not utilise rivers. A larger decrease in recharge will impact the sustainability of springs. Overally, catchment water yield will drop as evapotranspiration increases significantly. The headwater catchment will reduce its downstream contribution by half, meaning that wattle invasion could negatively impact riverine ecosystems.

The scenario demonstrates that wattle invasion will significantly lower erosion and sediment transport. This is important from a degradation point of view. Additionally, wattles invasion will result in a small increase in catchment surface runoff. This unexpected outcome could be explained by antecedent conditions caused by dense wattle cover or by the biomass loss emanating from replacing rangeland cover type with significantly higher biomass than forest type land cover. Nevertheless, the loss of rangeland cover significantly impacts livelihood in the catchment. Rangeland biodiversity provides grazing, fruit and several other provisioning ecosystem services that will be lost if wattle continues to invade. Therefore, wattle management is important from a hydrological and ecosystem services perspective.

CHAPTER 5 LOCAL PERCEPTIONS ON RANGELAND PROVISIONING ECOSYSTEM SERVICES IN THE TSITSA RIVER CATCHMENT, EASTERN CAPE

5.1 INTRODUCTION

Valuing of rangeland provisioning ecosystem services varies based on gender and livelihood strategy. In this chapter, we looked at how both male and female households value rangeland provisioning ecosystem services. Although many ES are deteriorating, they have always been important to people, as they are required to sustain livelihoods. The perceptions on how the threats to rangeland provisioning ecosystem services affect the supply and demand and how the different gender groups are impacted are critically important when understanding the rangeland provisioning ecosystem services in communal rangelands. This is because sustainable land management is dependent on balancing the supply and demand for ecosystem services among various land users (Yahdjian et al., 2015). Additionally, the supply and demand for rangeland provisioning ecosystem services may be perceived differently, depending on gender roles and uses. People's perceptions of ecosystem services are characterised by human values, attitudes, beliefs, behaviour, and demographic characteristics like gender, education, and age (Liu et al., 2022).

Importantly, the available literature on ES shows that gender aspects remain poorly explored (Cruz-Garcia et al., 2017), and many ES valuation studies do not consider gender and livelihood strategy. The communal rangelands in the Eastern Cape province, South Africa, are no exception to the threats posed by rangeland provisioning ecosystem services. The province continues to experience high land degradation in the form of soil erosion, decreasing vegetative cover, bush encroachment and invasive alien species. These threats continue to undermine the rangeland's ability to provide ecosystem-based livelihoods. Moreover, as rangelands continue to experience degradation, the supply of ecosystem services decreases, especially given the increased population pressure. Like many other communal rangelands, degradation negatively affects ecosystem services such as biodiversity loss, lower net primary production, deteriorating water quality, and lower livestock productivity, but also a reduction in ES supply (Khosravi & Escobedo, 2020). We conducted social surveys in the traditional villages of the Tsitsa River catchment to explore local people's perceptions of rangeland provisioning ecosystem services. Semi-structured one-on-one interviews in two traditional villages, namely, Lower Tsitsana centred around (30º 52'47.54" S, 28º 20' 47.31" E) and Basotho East centred around (30º 59' 52.69" S, 28º 30' 50.14" E) near Nqanqarhu Town under uLundini Local Municipality. The two villages were chosen because they demonstrate an ideal impact of the deterioration of rangeland provisioning ecosystem services due to the threat posed by soil erosion, alien invasive plants and overgrazing.

5.2 MATERIALS AND METHODS

5.2.1 One-on-one Interviews

One-on-one, semi-structured interviews were conducted to get in-depth information about the provisioning ecosystem services obtained from the rangeland, how important the ecosystem services are to both males and females (using the order of importance ranging from 1-5, with five being most important and 1 being least important) and the perceived threats to those ES? Lastly, the demographic information of the participants was also recorded to get not only gender perspective, but an overall perspective around rangeland provisioning ecosystem services. A total of 52 participants were interviewed, where 26 people were identified as males and 26 people were identified as females. The participants were interviewed based on their availability and willingness to participate.

5.3 RESULTS

5.3.1 Demographic characteristics of the households

The interviews consisted of 52 participants, including 26 females and 26 males. The participants ranged from 20 to 80 years, with 42% of the respondents falling between the ages of 61 and 80. All participants had lived and worked in their community. Only 4% of the participants had no education Most female participants had secondary education 54%, followed by primary education 38%, while 4% of participants had tertiary or no education at all. Forty-six percent of male participants had both primary and secondary education, while only 8% of the male respondents had tertiary education. Forty-two percent of females lived in houses made of bricks, followed by mixed materials 31%, while 27% lived in mud houses. The majority of males lived in houses made of mixed material 62%, followed by 23% of males living in bricks and 15% living in mud houses. In both villages, most participants (77% females and 50% males) depend on government social grants to sustain their livelihoods.

Table 5.1. Socio-demographics of participants for both study sites

Characteristics	Variable	Percentage (%)
Gender	Male	50
	Female	50
Age (Years)	20-40	29
	41-60	19
	61-80	44
	80+	8
Level of education	None	2
	Primary	42
	Secondary	50
	Tertiary	6
Type of houses	Mud	21
	Bricks	33
	Mixed materials	46
Source of income	Social grant	63
	Livestock	6
	Crop farming	8
	Salary	6
	Own business	2
	Private pension	2
	Crop and livestock	4
	Other	10

5.4 THE USE OF RANGELAND PROVISIONING ECOSYSTEM SERVICES

Table 5 2 shows the proportion of females and males using each provisioning ES. From the list of 19 provisioning ecosystem services provided, all the ecosystem services were reported to be used by both males and females. However, some of the ecosystem services were used more than others, for example, firewood was reported to be used by 100% of females, while bush meat was reported by 4% of females. Compared to males, who indicated use of wood for livestock enclosures (62%) and reeds (27%), females reported the use of wood for livestock enclosures (77%) and reeds (42%) for mats were relatively higher and varied. Differences in the use of bush meat, fencing timber, and water for irrigation were also reported. The use of wild vegetables and honey also differed between males and females. Seventy-seven percent of females indicated that they harvest wild vegetables, while 12% indicated that they harvest honey. On the other hand, 46% of males harvested wild vegetables and 54% harvested honey. However, the use of several ES such as wild fruit, mushrooms, firewood, wood for utensils and roof building, thatch grass, grass for brooms, grass for animal grazing, fresh water and natural medicine for both animals and humans did not differ between females and males.

Table 5.2. The percentage use of provisioning ecosystem services between females and males

Ecosystem services	Female (%)	Male (%)
Bushmeat	4	19
Wild vegetables	77	46
Wild fruit	69	62
Mushrooms	23	23
Honey	12	54
Firewood	100	92
Fencing wood	96	81
Wood for utensils	42	54
Wood for roof	77	69
Wood for livestock enclosures	77	62
Thatch grass	54	50
Reeds for mats	42	27
Grass for brushes	65	54
Grass for animal grazing	58	69
Medicinal plants for animals	42	46
Medicinal plants for people	65	73
Fresh water	81	73
Water for irrigation	85	65

Table 5.3 shows the rating of provisioning ES by order of importance by both genders. Females rated all ES (100%) as very important, indicated by 5, except for bush meat. Ecosystem services that were used daily were deemed to be of utmost importance by both genders. Firewood was mostly rated 5 (92%) by females reporting that they use it daily for heating and cooking, while males (92%) ranked firewood as being very important. Freshwater (100%) for drinking and irrigation (90%) received the second highest ratings. Wood for livestock enclosure and roof building had the highest percentage of people saying it is of low importance to them. Females gave the majority of ES a five (very important), for example, wild vegetables, fresh water, and medicine for people. A similar percentage of males (95%) rated fresh water and medicinal plants for people as very important, followed by 67% rating fencing wood as very important as well. There were similar percentages of people (33%) who said mushrooms were very important to them and 33% who said mushrooms were only slightly important to them. Fencing wood was rated to be important by 17%. Males (22%) reported that they only bought utensils and only gather wood for utensils when there was a traditional occasion that gave wood for utensils ratings of two.

Table 5.3. Female and male ranking of provisioning ecosystem services by order of importance (5 – very important, 1 – least important)

Ecosystem services	Female n=25 (%)					Male n=25 (%)				
	5	4	3	2	1	5	4	3	2	1
Bushmeat	-	-	100	-	-	40	-	20	-	40
Wild vegetables	90	5	5	-	-	92	-	8	-	-
Wild fruit	84	-	16	-	-	81	-	6	13	-
Mushrooms	33	17	17	-	33	33	-	17	33	17
Honey	67	-	-	33	-	46	8	38	-	8
Firewood	92	-	4	4	-	92	8	-	-	-
Fencing wood	60	12	16	-	12	67	17	13	4	-
wood for utensils	45	-	27	18	9	50	7	-	22	22
Wood for roof	70	10	5	-	15	65	15	15	5	-
Wood for livestock enclosure	70	5	10	-	15	75	-	13	6	6
Thatch grass	79	7	14	-	-	77	-	8	8	8
Reeds for mats	60	10	20	-	10	43	-	29	14	14
Grass for brushes	70	6	12	6	6	42	25	8	17	8
Grass for animal grazing	86	7	7	-	-	94	-	6	-	-
Medicinal plants for animals	82	18	-	-	-	83	8	-	8	-
Medicinal plants for people	71	18	-	6	6	95	-	5	-	-
Fresh water	100	-	-	-	-	95	-	5	-	-
Water for irrigation	90	5	5	-	-	88	6	6	-	-

Table 5.4 shows the threats to rangeland provisioning ecosystem services, as identified by females and males. The study reports that some of the ecosystem services identified were threatened by multiple threats within the study site. For example, 69% of females reported drought to have a significant impact on wild vegetables, while 62% of females also reported drought to have a significant impact on wild fruits. Similarly, females who collect fresh water for irrigation also reported drought and pollution as the biggest threats to freshwater. Moreover, fire was also reported the highest threat to woods (firewood, fencing wood) and grass (grazing grass, grass for brooms and brushes). Overharvesting of firewood and overgrazing were also reported by 23% of females as threats that increase soil erosion and increase the formation of gullies in grazing lands. Additionally, 42% and 38% of females reported that there was enough wood for fencing and making fire respectively, as they further reported that there was always wood available when needed. Moreover, drought was also reported to be a significant threat by males on water for irrigation (69%), fresh water for drinking (58%) and wild fruit and grass (50%) for animal grazing. Due to the impact of drought on fresh water, 77% of males reported that fresh water was affected by over-collection. Males (73%) also reported fire as a threat to both grass for grazing, 54% of males reported fire as a threat to firewood. Lastly, 58% of males reported that they did not experience any threats to honey, followed by 31% of those harvesting firewood.

Table 5.4. Threats experienced by both females and males.

Ecosystem service	A		B		C		D		E		F		G		H		I	
	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M
Bushmeat	-	4	4	15	-	-	-	-	-	-	-	4	-	-	-	-	-	-
Wild vegetables	69	42	15	4	-	-	-	-	4	4	-	-	-	-	-	-	-	-
Wild fruit	62	50	15	12	-	-	-	-	4	8	-	-	-	-	-	-	-	-
Mushrooms	4	8	4	4	-	-	-	-	15	12	-	-	-	-	-	-	-	-
Honey	4	-	4	-	-	-	-	-	15	58	-	-	-	-	-	-	-	-
Firewood	-	-	50	54	-	-	23	-	38	31	-	-	-	-	-	-	-	-
Fencing wood	-	-	54	-	-	-	8	-	42	19	-	-	-	-	-	-	-	-
Wood for utensils	-	-	35	38	-	-	-	-	8	8	-	-	-	-	-	-	-	-
Wood for roof	-	-	42	42	-	-	-	-	31	19	-	-	-	-	-	-	-	-
Wood for livestock enclosure	-	-	38	46	-	-	-	-	35	15	-	-	-	-	-	-	-	-
Thatch grass	-	-	42	50	-	-	-	-	-	8	-	-	-	-	8	-	-	-
Reeds for mats	-	-	35	23	-	-	-	-	-	4	-	-	-	-	4	-	-	-
Grass for brushes	-	4	54	19	-	-	-	-	8	4	-	-	-	-	-	-	-	-
Grass for animal grazing	27	50	54	73	8	8	-	8	-	-	-	-	23	58	-	-	-	4
Medicinal plants for animals	23	27	31	27	-	-	12	-	-	4	-	-	-	-	-	-	-	-
Medicinal plants for people	23	42	31	42	-	-	12	-	4	4	-	-	-	-	-	-	-	-
Fresh water	58	58	-	-	-	-	19	-	8	4	58	42	-	-	-	-	-	4
Water for irrigation	58	69	-	-	-	-	19	-	4	-	27	-	-	-	-	-	-	-

A – drought, B – fire, C – invasive species, D – overharvesting, E – no threat, F – pollution, G – gullies, H – overgrazing, I – erosion

5.5 DISCUSSION

5.5.1 Socio-economic characteristics of the households

The ecosystem services that people obtain from the environment have always been generalised, ignoring the fact that gender roles can be determinants that underpin their usefulness in an area. This ignorance undermines ecosystem services' value to both males and females in a community. For example, other studies have found that women are more vulnerable and reliant on ecosystem services than males because females are pressured to sustain households (Perez et al., 2015, Porsani et al., 2020). These findings are in line with our current study, where females value ecosystem services differently from males. However, others valued the same. Besides the social and cultural norms that restrict females from migrating in many rural societies, females tend to focus on ecosystem services that are closer to their homes, and help in improving household nurturing, while males are more likely to migrate, resulting in a phenomenon of left-behind females leading their households (Choithani, 2020). They also tend to value ecosystem services that are more outside the home nurturing, and those services that help generate income. Our findings are also supported by Shackleton et al. (2020) who reported that males are also more likely to participate in activities that require travelling away from their homes, whereas females are more commonly limited to spaces close to their homes due to household duties and taking care of children. The left-behind female-headed households in some communal rangelands can face significant challenges in accessing ES due to a lack of security of land rights (Schreckenberg et al., 2018). In some societies, women also face double exclusion due to a lack of agricultural assets and limited access to alternative sources of income outside of agriculture (Djurfeldt, 2018).

5.5.2 The extent of the use of rangeland provisioning ecosystem services

Both males and females widely use rangeland provisioning ecosystem services. The findings of this study showed that both females and males benefit from a variety of ecosystem services that provide for their livelihood needs throughout. For example, the results from this study report that fresh water, wood and grass are among the most used ecosystem services by both males and females. Moreover, females were reported to be using more ecosystem services than males in the two traditional villages. Our findings concur with studies by some authors (Martín López et al., 2012; Shen et al., 2015) who reported that females use more ecosystem services than males. However, some studies disagree with our findings. For example, Orenstein and Groner (2014) and Warren-Rhodes et al. (2011) reported that males were more aware of ecosystem services than females. We argue that males could be aware of the ecosystem services but could not be using them as they are not within their gender role domain. We add that these disparate results are probably the result of the interaction of gender with context and other aspects of identification, such as age, income, knowledge, cultural practices, information access and decision-making processes (Muhamad et al., 2014).

There is a small difference in the use of wood for livestock enclosures and reeds. Livestock enclosures are defined by Berglund (1975) as a temple where the ancestors' spirits dwell and look over their descendants. More females use wood for livestock enclosure but seemingly do not have more livestock ownership compared to males. This is an interesting finding, as one would expect more livestock enclosures to be reported by males than females, as females mostly move away from traditional practices and shift towards Christianity and would not prioritise livestock enclosure for ancestral dwelling. Moreover, one may not link the use of woods for livestock enclosure to ancestral dwelling, as livestock are a form of livelihood and need to be protected at night from theft. This is evident in the number of females who use grass for animal grazing. Additionally, women reported that they weave mats out of reeds for traditional events so that people can sit on them, while others sell these mats to earn money. Although a few males indicated that they make mats out of reeds, the majority emphasised that weaving is for females.

There is a substantial difference in the use of wild vegetables and honey. Females mostly reported this substantial use in wild vegetables. Our findings mirror those of a study in the Catalan Pyrenees by Calvet-Mir et al. (2016) which discovered that women value the ecosystem services provided by domestic and garden ecosystems. Females argue that such wild vegetables are essential to them since they are nutrient-rich and allow them to save a lot of money by not purchasing vegetables from the markets. Brown and Fortnam (2018) added that gendered division of labour in many rural communities is also one of the factors that cause females to use more wild vegetables because they have to prepare food for their family members.

5.5.3 Rating of rangeland provisioning ecosystem services according to their order of importance

Most of the ecosystem services are used similarly but are valued differently by both males and females. Males and females have reported a high value to most of the rangeland provisioning ecosystem services, accompanied by different reasons of importance. For example, females reported that they value thatch grass for roofing because it keeps the warmth in the houses warm compared to alternative corrugated materials. On the other hand, males reported that thatch grass is important to them because they build lodges out of it for initiates to stay in during their seclusion period. Our findings echo those reported by Cruz-Garcia et al. (2019) and suggest the importance of valuing ecosystem services according to gender, as its importance is perceived differently because they demonstrate the significance of gender consideration when evaluating ES.

Similarly, other studies also show that the ranking of ES is gendered. For instance, Tadesse et al. (2014), and Cruz-Garcia et al. (2019) reported that females value firewood more than males do in Southwestern Ethiopia while males value building material. Another similar study is found by Githiora-Murimi, (2022) which shows that women value plants and shrubs for the flow of firewood much higher than men. In contrast, this study shows that there is no difference in how females and males value firewood and construction material (fencing wood, thatch grass). This is also supported by Cruz-Garcia et al. (2019), who report that there is no significant difference in how males and females value firewood. However, females emphasised that firewood is less expensive than alternate energy sources, while males just mentioned that they use firewood for heating.

Contradictory to our findings, Pearson, (2019), Yang et al. (2018) reported that females tend to have more knowledge of the medicinal uses of plants than males. However, these contradictions may be related to context and the type of medicine obtained from the rangelands and their relative specific use to humans. Females have a higher valuation of medicinal products and water resources compared to males (Cifuentes-Espinosa,2021), which contradicts with our study in the notion that women place a high value on natural medicine, but they are consistent with those regarding women's high value for water resources.

5.5.4 Threats to rangeland provisioning ecosystem services

According to the Millennium Ecosystem Assessment, 60% of the ecosystem services people use are continuously degrading (Chen et al., 2016). The findings from this study report that fire is one of the factors that threatens and undermines the provisioning of ecosystem services from the rangelands. Both males and females acknowledged that fire negatively impacts grazing fields. Fire seems to threaten rangeland, provisioning ecosystem services in many other places. For example, Kyriazopoulos et al. (2013) reported that 47% of the respondents in their study thought fire posed a high threat to rangeland in the Viotia prefecture of Greece. However, patch burning is frequently a contributing factor in wildfires in rangelands and may be used to increase the amount of available fodder and enhance the forage quality (Kyriazopoulos et al., 2013). If such fire is inadequately controlled, it could spiral out of control and threaten other ES like firewood. These wildfires, as reported in our findings by the participants, are always unknown of where and when they started. In addition to fires, climate change is one of the most important emerging issues and affects rangeland ecosystems (Rueff, 2014). Extreme droughts and floods are becoming more common in rangelands, frequently characterized by substantial spatial and temporal fluctuation of temperatures and rainfall (Derner & Augustine, 2016). Prolonged drought may decrease the diversity and composition of herbaceous plants, which could accelerate the deterioration of rangelands Abdelsalam, (2021), further undermining their ability to generate the much-needed ecosystem services. The findings from our study are no exception, drought was the second most mentioned threat by females, primarily affecting wild vegetables. While males reported that drought primarily affects irrigation water, our findings contradict with the study by Simberloff et al. (2013) which reports that alien invasive species are considered the second most important threat to rangelands. Both genders are equally affected by drought on freshwater but females face the most adverse effects due to gender roles in the households. The water requirements for females and their responsibility for water management in households include household water use, and personal hygiene, to mention a few.

We further report that males and females are equally affected by Alien invasive species taking over the rangelands. Our findings report that alien invasive species (*Acacia mearnsii*) affect grazing land. Other studies report that alien invasive species reduce the growth and fitness of native plants in rangelands (Di Tomaso et al., 2013; Pathak et al., 2021). As males are primarily responsible for herding animals, they are expected to be more affected by invasive species that affect grazing land. When respondents were asked about their knowledge of the origin of the species, both genders could not tell the source of invasive species. According to Gwate et al. (2016) *Acacia mearnsii*, popularly known as wattle, has reportedly been spread worldwide by various techniques, including transference, diffusion, and dispersion. Gwate et al. (2016) further revealed that the grass production of the Kei and uMzumvubu catchments was negatively impacted by *Acacia mearnsii*. However, despite the impacts of invasive species on grazing land, participants reported using the wattle for fencing and kraal making.

Freshwater is affected by overuse, drought, erosion and pollution. The study by Du Preez and Van Huyssteen, (2020) also highlights that water quality in many regions of the world is threatened by overuse, misuse and pollution. This study reports that waste from animal excretion, dust from soil erosion, and children playing in the river are why water and water sources are polluted. These mismanagement and threats to water sources have significant impacts as they result in water scarcity. According to Siddhartha (2010), the lack of water becomes an issue for women since it also restricts their ability to cultivate land. They must split their limited time between gathering water and cultivating. The study further states that females are more likely than males to come into contact with water, hence they are more affected by water pollution.

The growth of thatch grass and reeds was reported to be threatened by frequent overgrazing. Similar to our findings is Lemaire et al. (2011) who also report that overgrazing by cattle throughout the growth season is harmful to the establishment of thatch grass. Thatch grass production is not a problem on privately owned land and in protected areas where grazing can be controlled, according to Lemaire et al. (2011), but it can be a declining resource in rangelands where customs and rules may not strictly regulate utilisation of resources. Males in our study also reported that they do not get a lot of thatch grass from the rangelands because the fields are no longer cultivated. Grazing immediately before harvest lowers the amount of thatch that is available but grazing for a brief time after harvest does not have an adverse effect on the long-term productivity of thatch grass (Lemaire et al., 2011).

Overgrazed rangelands are characterised by unpalatable plants, greater soil erosion, and a decline in significant forage plants (Getabalew & Alemneh, 2019). When grazing is concentrated in one part of a rangeland, bare soil patches and exposed areas without vegetation cover are left behind, making the rangelands more susceptible to wind and water erosion. Male participants reported that wind and water erosion affect grazing land and water quality. These results contradict with the results found in Bangladesh by Rahman and Haider (2020), who found that females are more vulnerable to soil erosion than males. These differences in the results link to gender roles. It is believed that erosion increases the household workload for women by causing the loss of utensils and harvesting land (Rahman & Haider, 2020). According to the male participants, the soil structure is disrupted by erosion, causing the formation of gullies, which cause livestock injuries. Males could identify gullies because most of the males owned livestock, and some oversaw herding female-owned cattle, which made males engage more with grazing fields.

5.6 CONCLUSION AND IMPLICATIONS RANGELAND MANAGEMENT

The value and use of rangeland provisioning ecosystem services by different genders has not been the subject of many studies; This study offers a contribution on how rangeland provisioning ecosystem services are perceived, valued and contribute to different gender types within the same community. Beyond finding the ways that females and males utilise and value ecosystem services differently, this study looked at why ecosystem services form a significant part of people's livelihoods based on their gender roles. This study found that rangeland provisioning ecosystem services are used similarly but are valued differently by both males and females. The value of ecosystem services relates to socially constructed differences between females and males based on their roles, responsibilities and daily activities. The argument is that gender, including roles and stereotypes, is an important criterion that needs to be considered in research to explain gender differences in the use and value of ecosystem services. The acknowledgement of gender differences could help in making sure that interventions that seek to improve natural resources while realising the sustainable development goals are gender inclusivity and equity for the sustainability of life on land. These may be facilitated by identifying and prioritising threats for intervention, which an understanding of the various impacts of the identified threats on females and males should inform. In a communal rangeland system, effective participation from the affected village could be mobilised to set up rules and bylaws that could control the use of other ecosystem services and management approaches that help reduce the threats such as fires and overgrazing to improve the generation of rangeland ecosystem services.

CHAPTER 6 PARTICIPATORY MAPPING OF RANGELAND PROVISIONING ECOSYSTEM SERVICES

6.1 INTRODUCTION

To understand the value of ecosystem services to rural people, the study used participatory mapping, combining cartography with public engagement to map people's knowledge, experiences, and goals and facilitate the development of new knowledge (Weyer et al., 2019). The goal of using participatory mapping is not to only produce maps but to also empower and include people by recognising their perspectives on threats to rangelands (Codato et al., 2017). Participatory mapping, in its various forms, provides numerous opportunities for communities to co-create knowledge. By involving holders of local and indigenous knowledge in a participatory mapping process, researchers can translate certain types of scientific knowledge in a discursive manner (Weyer et al., 2019). Participatory mapping is commonly used to visualise and understand the information presented in maps without requiring the use of the literature by making visible relationships between land and rural communities (Weyer et al., 2019).

Drawing from the above, this study aimed to assess perceptions of the location of ES, supply, demand and threats to rangeland ES in the Tsitsa River Catchment. Taking pre-emptive actions against threats to rangelands will help improve people's livelihoods and sustain the ES for the future.

The workshops were conducted in two traditional villages in the Tsitsa River Catchment and the following were the key questions guiding the workshop discussions:

(1) What provisioning ecosystem services are derived from the rangelands?
(2) Where in the rangelands are the provisioning ecosystem services derived?
(3) Is the current level of supply sufficient to meet users' demands?
(4) Who is more reliant on which provisioning services?
(5) Has supply and demand changed over time?

The focus group discussions were conducted in a participatory manner where local people were shown on the map, the areas where they derive the rangeland ecosystem services, their threats and perceived supply and demand for the mentioned ecosystem service. The traditional areas were representation areas within the Tsitsa Catchment which were chosen based on the level at which rangeland ecosystem services are threatened. Participants from the two traditional villages were recruited through a stratified random approach by sending invites to the village heads asking them for permission for rural people to participate in a series of workshops. These workshop invitations were open to anyone who resided in these respective villages. We used Google Earth Engine to generate maps and put boundaries within the villages of interest.

6.2 MATERIALS AND METHODS

6.2.1 Focus group discussions: participatory mapping

A total of seven people from Lower Tsitsana and a total of 25 participants arrived in Khohlopong village, Basotho traditional village. Participants in Lower Tsitsana were grouped into two groups and in Khohlopong village, they were grouped into three to have varied perspectives. With the help of facilitators, each group was asked to locate from the map provided the provisioning ecosystem services and the areas they derive each of the services from the rangeland of the map supplied. To locate the provisioning ES, participants pointed to areas where they derived the services and a sticker with the name of the service was written and pasted on the identified area. This procedure was done for all the services they derived from the rangeland. After the mapping session, participants were asked questions to engage in a focus group discussion. This was done to get different perspectives from participants regarding threats, supply and demand for provisioning ES they derived from the rangelands.

Figure 6.1. Focus group discussion in Lower Tsitsana Village, Tsitsa River Catchment

Figure 6.2. Focus group discussion in Khohlopong Village, Tsitsa River Catchment

6.3 RESULTS

6.3.1 Participatory mapping of provisioning ecosystem services

Ecosystem services at Lower Tsitsana rangeland are widely distributed as shown in Figure 6.3. Of the 35 pins (representing ecosystem services and threats) mapped, 18 yellow pins represented provisioning ES both females and males derive from Lower Tsitsana rangeland. Only two of these ES (namely freshwater and thatch grass) were marked within the boundary that was set. The boundary was outlined for participants but they claimed that they derived most of the ES far from their homes. Villagers have to travel a distance to get some of the ES. Nine of the red pins represent severe threats to ES. Fire appeared to be the most severe threat negatively affecting more than two ES. Overgrazing, floods and soil erosion were the only threats marked within the boundary. Nine less severe threats were marked, two of which were within the boundary (erosion and overgrazing). At Basotho East, Khohlopong village, the ES were also widely distributed (Figure 6.4). Thirty-nine provisioning ES and threats were mapped. Twenty of the pins were ES and the other 19 were threats. Nine of the ES were marked within the boundary, while eleven were marked outside the boundary. Most of the threats mapped were severely, negatively impacting the ecosystem services. In this site as well, fire was the most significant threat negatively impacting ES.

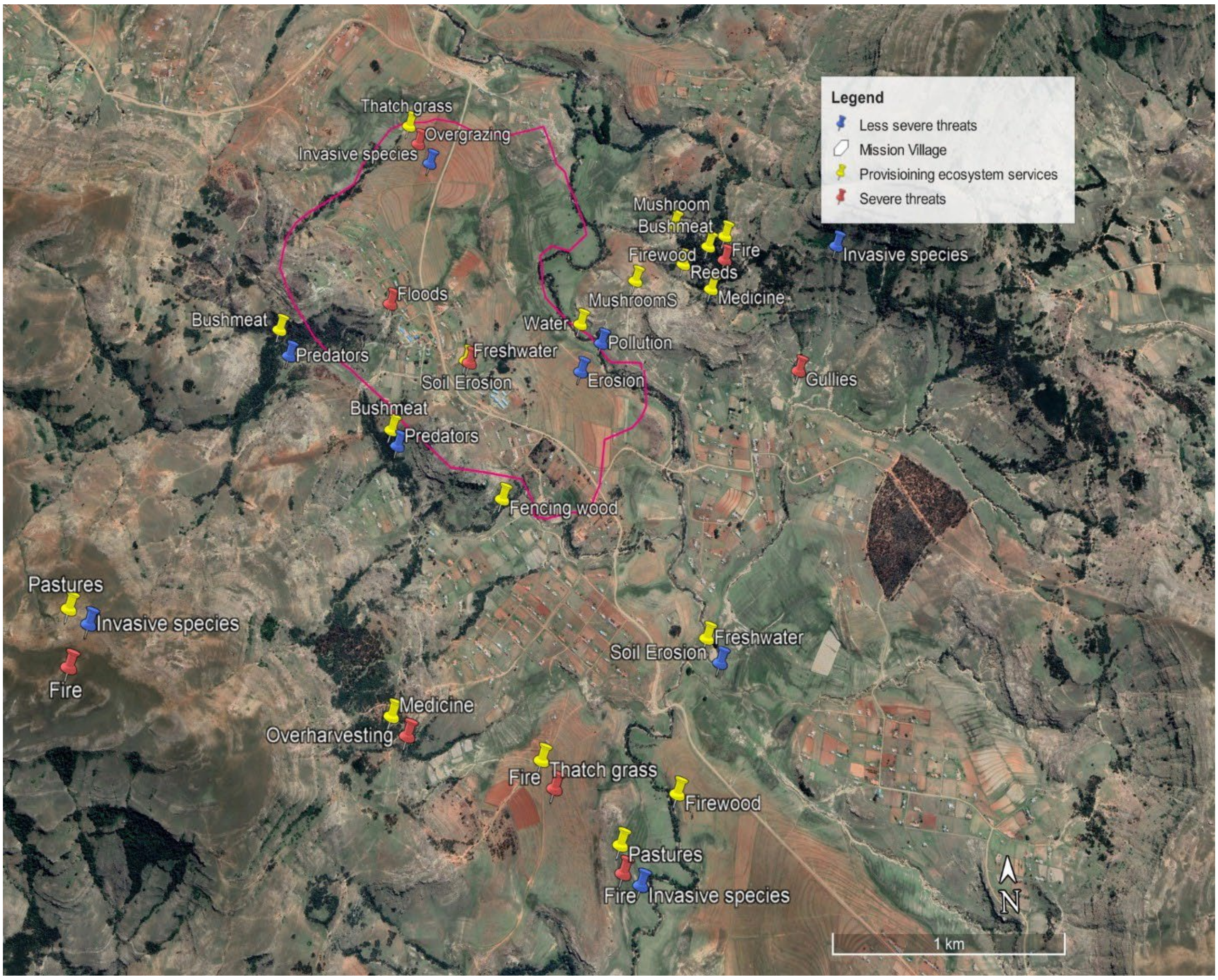

Figure 6.3. An illustration of the rangeland provisioning ecosystem services with their associated threats in Lower Tsitsana Traditional village.

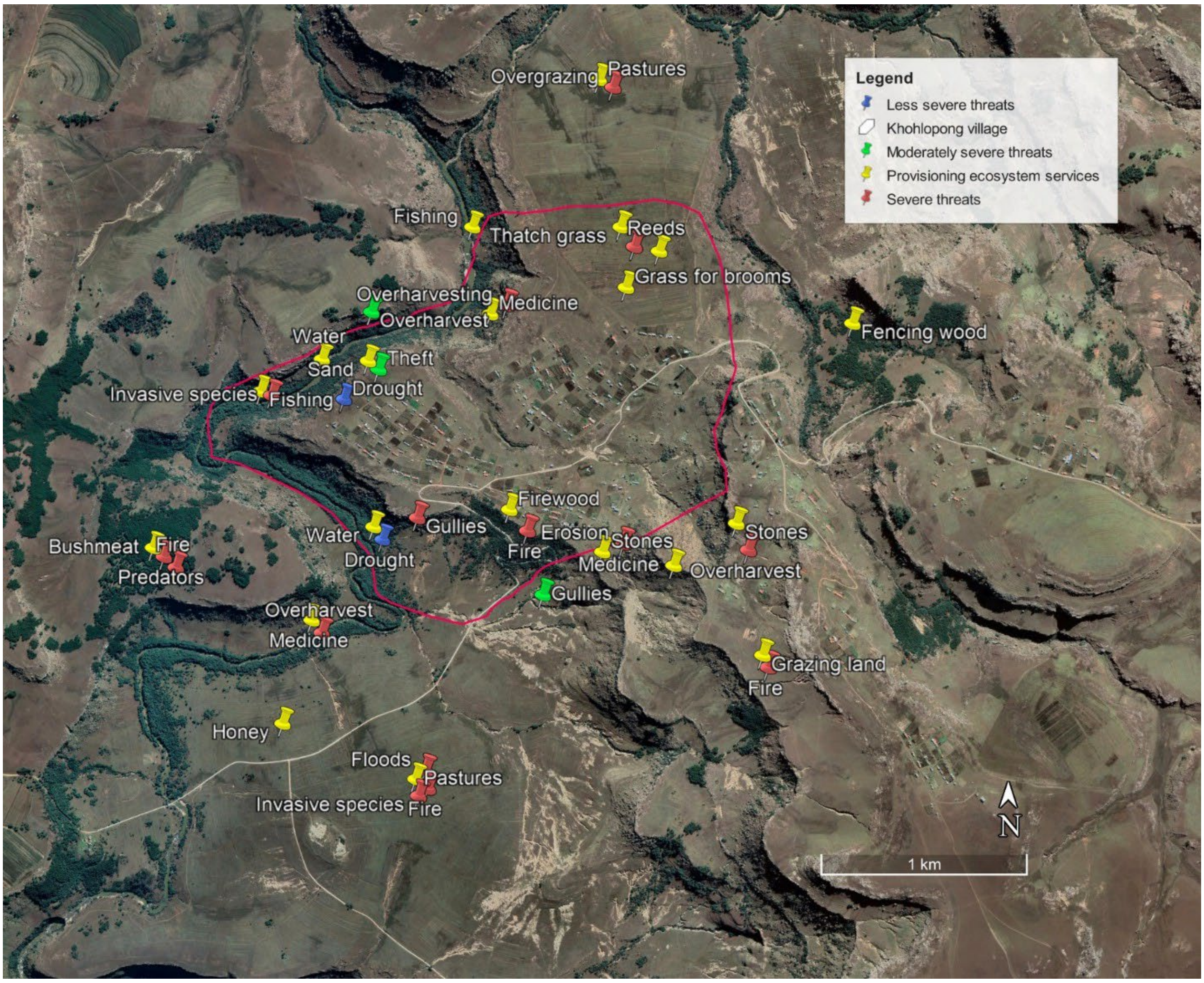

Figure 6.4. An illustration of the rangeland provisioning ecosystem services with their associated threats in Basotho East Traditional village.

6.3.2 Distribution of rangeland provisioning ecosystem services

The distribution of the provisioning ES in Lower Tsitsana village is widely dispersed (Figure 6.5). Only three of these services (water and thatching grass) were marked within a polygon demarcating the village. The polygon outlined was used a as boundary for participants to report the services they derive. Participants indicated that they derive most of the services far from their village as most of the pins are scattered distant from their village boundary. Out of 18 red and green pins representing supply levels mapped, fencing wood and firewood as well as other services found in distant areas such as mountains were reported to have sufficient supply. Meanwhile, the remaining services were perceived to have insufficient supply.

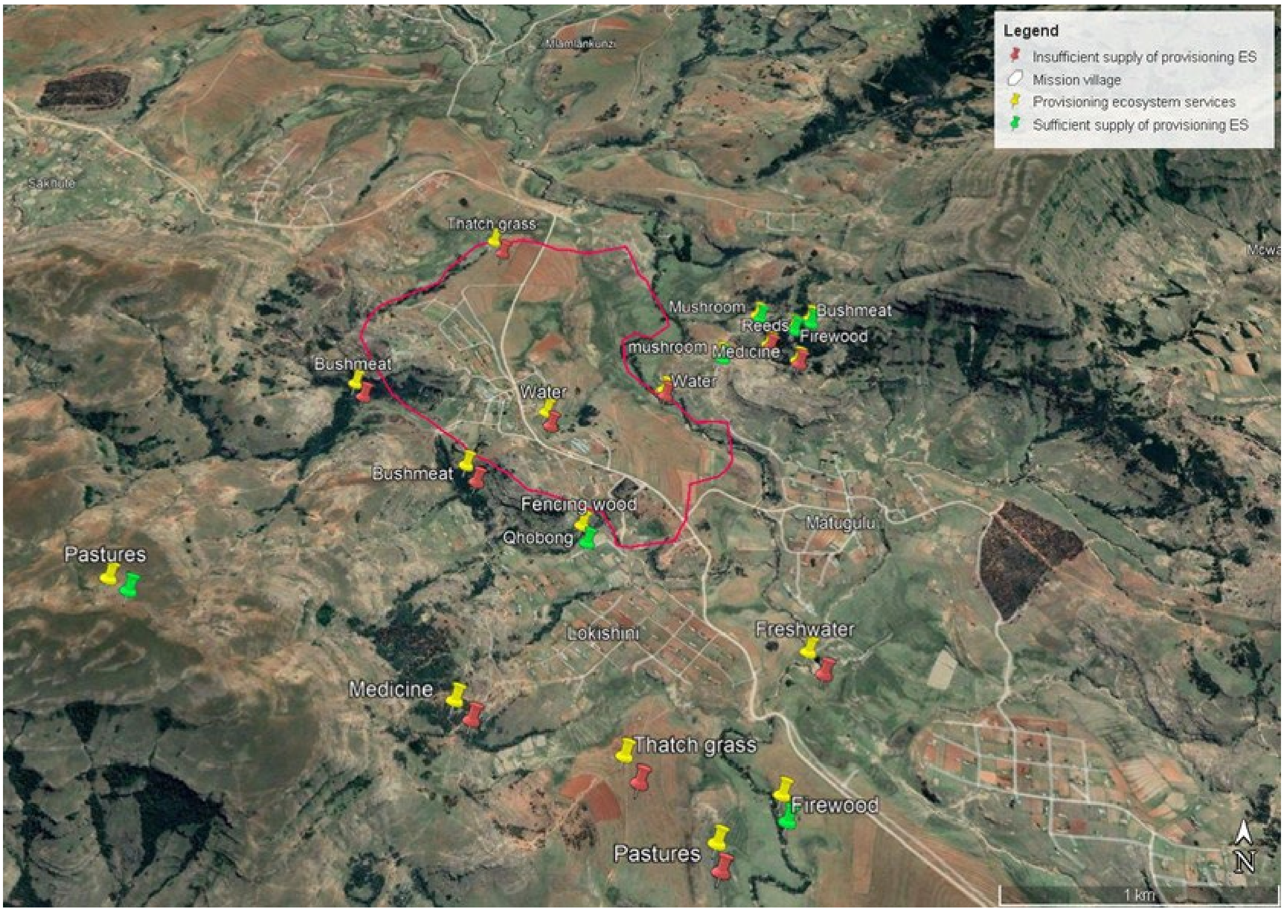

Figure 6.5. Primary source areas of provisioning ecosystem services in Lower Tsitsana village

Provisioning ES mapped in Basotho traditional village was widely also distributed. Out of 34 provisioning ES and supply pins mapped, a total of nine provisioning ES pins were distributed inside the village boundary, while the remaining nine were scattered around the boundary. Firewood and fencing wood were the only two provisioning ES with sufficient supply.

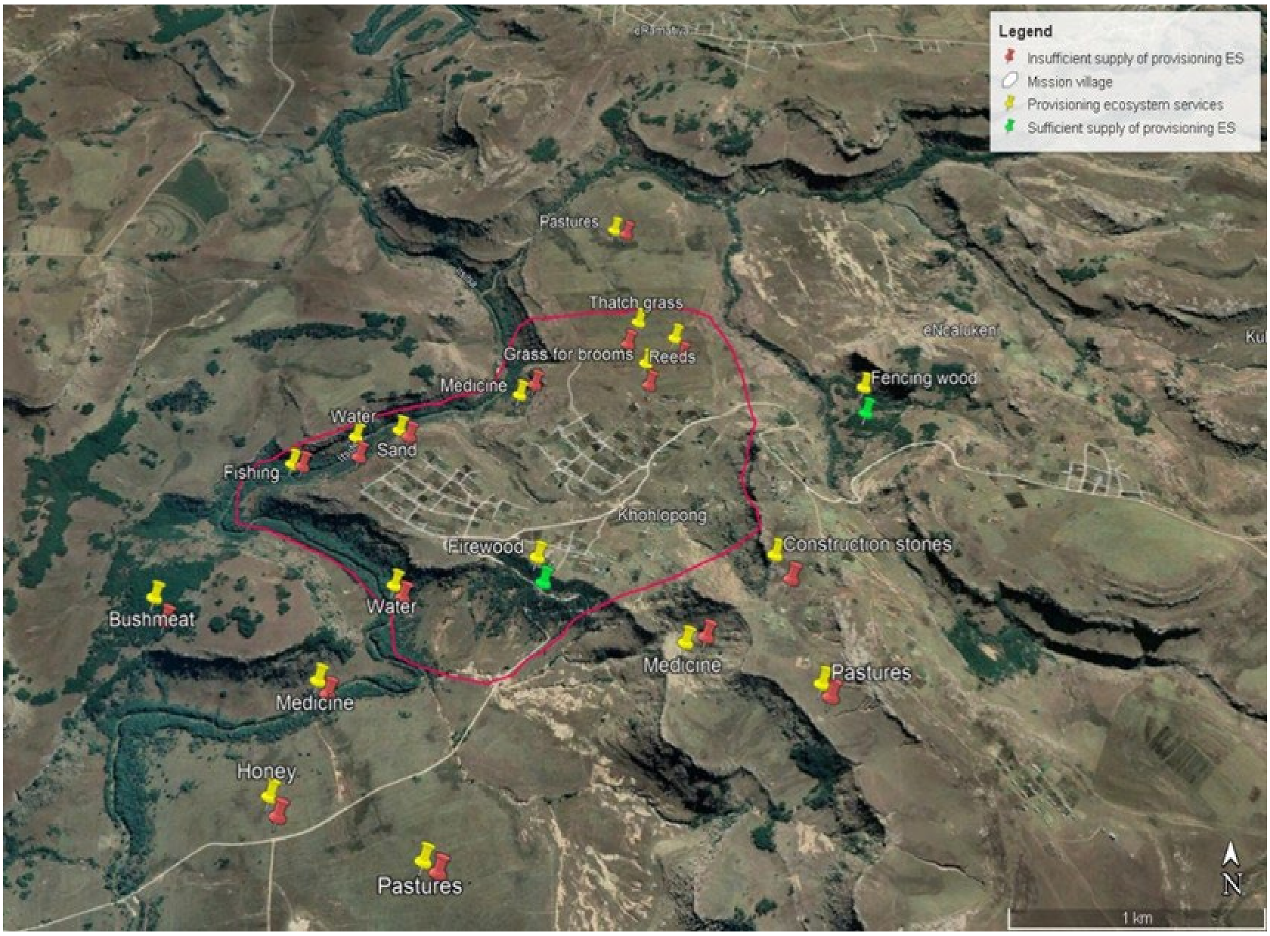

Figure 6.6. Primary source areas of provisioning ecosystem services in Basotho village

6.4 DISCUSSION

6.4.1 Mapping of provisioning ecosystem services

The use of participatory mapping in ES assessment is rising (Paudyal et al., 2015). Using participatory mapping, we identified ESs provided by the Tsitsa rangelands based on local perceptions. The resultant maps depict the general location of the ES and do not explicitly recognise its gendered location. These ES were distributed in various locations with most ES located at the forest and fallow areas. Similar results were found in the province of Napo in central-northern Ecuador (Delgado-Aguilar et al., 2017). How the location of ES is perceived depends on who was participating, where they reside and how they interact with the landscape. The minimum distance between an ES location and the centre of the village is approximately 0.3 km at Lower Tsitsana and 0.6 km at Basotho East while the maximum distance between the ES location and the centre of the village is 2,5 km at Lower Tsitsana and 1,9 km at Basotho East. Four ES of high priority were found in Tsitsa catchment (both villages), namely, timbre, firewood, grazing land and freshwater. The forests are where most of the timbre and firewood are produced while springs are found all over the place and provide freshwater. Similarly, grazing areas are widely dispersed but notably distant from homesteads. The study in Central Nepal by Paudyal et al. (2015) demonstrates that food is produced everywhere throughout the landscape, while the production of fencing wood is concentrated close to river banks. The current use of ES in the two villages was successfully elicited through the interactive mapping activity. However, most participants found it challenging to map the distribution of ES because they came from other villages. Only a few studies use participatory mapping to assess the threats to ES (Shrestha et al., 2021). It is crucial to employ participatory mapping to evaluate threats to ES because it guards against biases when determining management areas of priorities and guarantees that ES continues to be useful (Shrestha et al., 2021). The key locations where ES are found are severely threatened by fire, overharvesting, soil erosion, and overgrazing, moderately threatened by theft, erosion gullies, overharvesting and less threatened by invasive species, wind erosion, overgrazing, drought, gullies and predators.

6.4.2 Spatial distribution of provisioning ES and levels of supply

The distribution of provisioning ES mapped by participants reported fodder, firewood and water as the most commonly derived provisioning ES in the rangeland. This is in line with a review of mapping ES by Egoh et al. (2012) which indicated that from 67 studies conducted in South Africa, 40% of these studies reported water and fodder as the most common services derived. This is mainly because many people depend greatly on these services for domestic uses. This was further indicated during the household interviews. The findings from participatory mapping also indicated a trend of decreasing supply of several provisioning ES in the study area, which is consistent with prior research at larger scales, which shows a trend of reducing ES supply globally (e.g. de Groot et al., 2002; MEA, 2005; Reyers et al., 2009; Egoh et al., 2011). However, according to the respondents, there is an increase in the supply of some provisioning ES such as firewood and fencing wood. These services increased due to the invasion of silver wattle (*Acacia dealbata*) in the study area (Ngorima & Shackleton, 2019). These findings contradicted with the study by Paudyal et al. (2019) where it was mentioned that the provision of wood is declining in many communal areas. Although participants mapped several grazing lands that provide fodder as one of the services they derived, it was reported that in some areas, the supply of fodder was insufficient due to overgrazing, whereas in other areas, such as mountainous areas, the supply was to be sufficient. Respondents indicated that this results from all livestock owners and people from villages beyond the catchment having equal access to communal lands to harvest or allowing livestock to graze in communal grazing areas. They further provided justifications such as having no management interventions or unclear rules for grazing areas around their villages. Similar findings were reported by research carried out by Kirkman et al. (2003) in natural rangeland forages of KwaZulu-Natal South Africa.

Additionally, it was reported that many of the services were derived far from the villages. Respondents indicated that this is because services such as fodder and medicine are threatened. For instance, fire was posed as a threat to a decline in the supply of medicine and fodder. Similarly, Tuague and Kreuter (2020) found that the decline in ES such as medicine and fodder in rangelands is not caused by overstocking and overgrazing only but the decline is also caused by fire as a threat.

6.4.3 Livestock grazing association

After an illustration of the areas that are most vulnerable to providing provisional rangeland ecosystem services, rural people mentioned that efforts to rest and restore rangelands are ongoing. The Lima through the herding for health has been facilitating the formation of grazing associations where communities assign certain areas within their rangelands to allow for rest and recovery. The established enclosures also help to demonstrate the importance of having rangelands under rest even though the project could only report based on a single-year monitoring. During the participatory mapping of ecosystem services, some areas that could be prioritised for rangeland management for improved ecosystem services were identified.

CHAPTER 7 CONCLUSION AND RECOMMENDATIONS

7.1 CONCLUSIONS

In conclusion, communal rangeland systems continue to experience transformation through structure, productivity, rainfall variability, and changes in species composition. Because of these changes, many negative consequences, such as increased runoff and accelerated erosion, negatively affect rangeland productivity. The state of rangeland degradation is contested in South Africa, and there is a need for further studies to unravel rangeland integrity and possibly explain why the communal rangeland system, which is perceived to be run down, continues to support livestock production for the black majority. Government interventions looking at improving rangeland management, following land reform, should consider community involvement in adopting and managing the common resource. There is currently limited effort by national and provincial agricultural agencies to improve and build community capacity to better understand land degradation and the processes involved in rehabilitation and managing the land. Policies continue to be a top-down approach with minimal community involvement on a needs-based analysis of services derived from rangeland and the incentives for properly managing the rangelands for improved ecosystem services. In addition, bottom-up approaches supported by rangeland resource monitoring, such as degradation monitoring and rangeland assessments, followed by improved vegetation cover and control of invasive alien vegetation, should be strengthened at community levels through government intervention.

7.2 RECOMMENDATIONS

- The project timeframe was short to completely explore the productivity of the rangelands
- To explore the full benefits of grazing exclusion, several seasons are required to monitor the response of soil variables
- Community-based research which requires community participation requires more time for a complete change in the biophysical environment.

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APPENDIX A CONFERENCES AND PRESENTATIONS

Ms Esihle Gotye, Supervised by Dr David Gwapedza attended and participated at the South African Hydrological Conference held in Pretoria. Ms Gotye presented her research work and won a Best Poster Presentation award.

Figure 7. Esihle Gotye (second from right), with Dr David Gwapedza, Dr Jane Tunner and Gravira attending the South African Hydrological Conference, Pretoria.

The Department of Environmental Science at Rhodes University hosted an annual Research forum, where Asisipho Khinkwayo and Dikeledi Phooko presented their work. Ms Khinkwayo won a prize for being one of the best-presented research work.

Figure 8: Dikeledi Phooko from (left), Dr Bukho Gusha and Asisipho Khinkwayo attending the Department of Environmental Science Research Forum, Rhodes University.

AGENDA FOR THE WORKSHOP

Workshop Outline

Gusha B, Gwapedza D, Khinkwayo A, Phooko D, Jackson C, Gotye E and Ntsangase A.

1. WORKSHOP PURPOSE

This workshop is intended to understand the benefits that local people derive from the landscape. Their threats, perceived supply and demand for the rangeland ecosystem services and mitigation strategies.

2. WORKSHOP LOGISTICS

Suggested Venue: Mission Village Hall in Lower Tsitsana and Sikonyela Hall in Khohlopong village

Suggested Time: 28 and 29 July 2022

Suggested Team: Bukho Gusha, David Gwapedza, Asisipho Khinkwayo, Dikeledi Phooko, Esihle Gotye, Anele Ntsangase, node CLOs, headmen.

Suggested Food arrangements: CLO to make sure a cooked lunch is prepared. Tea and biscuits are to be served in the morning

Suggested travel arrangements: Rent a car from BLUU.

Suggested stationary: Flipchart paper, colored pens, Sticky notes, Prestik, camera, recordings, Maps

3. WORKSHOP OUTLINE

Table 1 – Workshop outline draft

Time	Activity	Description	Facilitator
DAY 1 and 2			
09:00-90:30	Set up and coffee/tea while members arrive	The team meets at the venue, greets the hosts	Whole team
09:30-09:45	Introductions	Who are we? What are we doing? Why are we doing it? Where are we working? Brief background of rangeland ecosystem services.	Bukho Gusha
09:45-12:30	(First session on Treats to rangeland ES) Tell us about your rangeland ES	Community members divide into small groups and a facilitator asks participants to show from the map what ES they derive and where in the rangelands they derive those.	Team effort to facilitate. (Both Dikeledi and Asisipho collecting the same data)
12:30-			
13:15-14:30	Second session on supply and demand of ES	Community members divide into small groups of livestock vs non-livestock owners	Dikeledi session (Team to facilitate)
14:30-15:30	Anele session		
	and departure		

4. PROMPT QUESTIONS TO ASK

(1) What provisioning ecosystem services are derived from the rangelands?

(2) Where in the rangelands are the provisioning ecosystem services derived?

(3) Is the current level of supply sufficient to meet users' demands?

(4) Who is more reliant on which provisioning services?

(5) What are the mitigation strategies used?

PROMPT SHEET FOR PARTICIPATORY MAPPING OF RANGELAND PROVISIONING ECOSYSTEM SERVICES FOCUS GROUP DISCUSSION

1. What provisioning services are derived from the rangelands?

2. Show me in the map where in the landscape do you derive these provisioning ecosystem services?

3. Are you deriving sufficient services from the rangelands enough to meet human demand?

Ecosystem services	Response

4. Are there people who depend more on either of the mentioned services? If yes, who?

5. Has the supply of these services changed in the last 5-10 years?

6. Has the demand for these services listed changed in the last 5-10 years?

7. How has the change in both demand and supply affected your livelihoods?

GENDERED PERCEPTION OF THREATS TO RANGELAND ECOSYSTEM SERVICES IN THE TSITSA RIVER CATCHMENT

Provisioning ecosystem services	Name the provisioning ecosystem services you derive from the rangelands. (Benefits extracted from your surrounding environment)	Why is the ecosystem service important to you?	How frequently do you use the ecosystem service? Daily, weekly, monthly.	Rank the ecosystem services you derive in order of importance from 1-5. One being the most important and five being the least important
1.Bushmeat				
2.Wild vegetables				
3.Wild fruits				
4.Mushrooms				

5.Honey				
6.Wild insects				
7.Firewood				
8.Fencing wood				
9.Wood for utensils				
10. Wood for roof building				
11.Wood for livestock enclosure				
12.Thatch grass for roofing				
13.Reeds for mats				

14.Grass for brooms/brushes				
15.Grass for animal grazing				
16.Medicinal plants for animals				
17.Medicinal plants for people				
18.Fresh water				
19.Water for irrigation				

Provisioning ecosystem services	Threats	Sources of threats	How do the threats affect your livelihood?	Are there any interventions to manage the threats? Yes or No
1.Bushmeat				
2.Wild vegetables				
3.Wild fruits				

4.mushrooms				
5.Honey				
6.Wild insects				
7.Firewood				
8.Fencing wood				
9.Wood for utensils				
10. Wood for roof building				
11.Wood for livestock enclosure				
12.Thatch grass for roofing				

13.Reeds for mats				
14.Grass for brooms/brushes				
15.Grass for animal grazing				
16.Medicinal plants for animals				
17.Medicinal plants for people				
18.Fresh water				
19.Water for irrigation				

Provisioning ecosystem services	Interventions	Rank the threats according to their severity. One is the most severe and five	What initiative/ management strategies do you have as a community to	Do people comply with the management strategies? Yes, No, or I don't know

		being the least severe.	manage the threats?	
1.Bushmeat				
2.Wild vegetables				
3.Wild fruits				
4.mushrooms				
5.Honey				
6.Wild insects				
7.Firewood				
8.Fencing wood				
9.Wood for utensils				
10.Wood for roof building				

11.Wood for livestock enclosure				
12. Thatch grass for roofing				
13.Reeds for mats				
14.Grass for brooms/brushes				
15.Grass for animal grazing				
16.Medicinal plants for animals				
17.Medicine plants for people				
18.Fresh Water				

19.Water for irrigation				

Provisioning ecosystem services	If not, what do you think is the reason for them not to comply?	What happens to people who do not follow the management strategies?	Do you need any help with managing the threats? Yes or No	If yes, who do you need help from?
1.Bushmeat				
2.Wild vegetables				
3.Wild fruits				
4.mushrooms				
5.Honey				
6.Wild insects				
7.Firewood				

8.Fencing wood				
9.Wood for utensils				
10.Wood for roof building				
11.Wood for livestock enclosure				
12. Thatch grass for roofing				
13.Reeds for mats				
14.Grass for brooms/brushes				
15.Grass for animal grazing				
16.Medicinal plants for animals				

17.Medicine plants for people				
18.Fresh Water				
19.Water for irrigation				

Provisioning ecosystem services	What can be done to help you with managing the threats?			
1.Bushmeat				
2.Wild vegetables				
3.Wild fruits				
4.mushrooms				

5.Honey				
6.Wild insects				
7.Firewood				
8.Fencing wood				
9.Wood for utensils				
10.Wood for roof building				
11.Wood for livestock enclosure				
12. Thatch grass for roofing				
13.Reeds for mats				

14.Grass for brooms/brushes				
15.Grass for animal grazing				
16.Medicinal plants for animals				
17.Medicine plants for people				
18.Fresh Water				
19.Water for irrigation				

	QUESTION	RESPONSE
1	Age range	
2	Gender	☐ Female ☐ Males ☐ Other Specify
3	Highest level of education	☐ Illiterate

		Primary level Secondary level Tertiary level
4	Number of years lived in the village	
5	Type of houses	Mud Bricks Mixed material
6	Sources of income	Social grant Livestock farming Crop ming Salary Own business

Socio-demographic information