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# Social–Ecological System Understanding of Land Degradation in Response to Land Use and Cover Changes in the Greater Sekhukhune District Municipality

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**Abstract:** Land degradation is a major risk to the sustainability and functioning of socioecological systems (SES), especially in arid/semiarid regions. By understanding a system and its interlinkages, the socioecological approach offers an innovative way to explore degradation. This is achieved through a synergistic analytical approach to improve the ability of identifying and understanding systems, predicting their behaviour, and modifying them to achieve the desired effects. This research provides a roadmap for an integrated interdisciplinary approach that is a critical factor in understanding the drivers of land degradation. It can be used to determine appropriate land management action. The aim of this study was, therefore, to apply an integrated SES approach to a degraded rural semiarid context to address the land degradation problem using the Greater Sekhukhune District Municipality in South Africa as a case study. The Drive Pressure State Condition and four Responses ($DPSCR_4$) framework (modified from Drive Pressure State Impact and Response (DPSIR)) was used as the SES to assess land degradation. Key informant interviews, focus group discussions with local pastoralists and traditional authorities, and the scientific literature were triangulated to systemically analyse $DPSCR_4$. Land degradation neutrality (LDN) was integrated into the framework to draw conclusions on sustainable land management (SLM). The results show that the main anthropogenic activities driving land degradation are overgrazing, land tenure, poverty and disenfranchisement, unsustainable land use, and cropland abandonment, which favour bush encroachment. Natural factors such as topography, dispersive duplex soils, and climate variability and change predispose the district to soil erosion and gully formation. In combination with human activities, this exacerbates land degradation. The study recommends measures to enable informed integrated land use planning and management using the $DPSCR_4$ and LDN frameworks to improve landscape conditions in rural semiarid regions and provide sustainable livelihoods for the rural poor in developing countries who depend on natural resources.

**Keywords:** land degradation; social–ecological systems; $DPCSR_4$ (DPSIR); land degradation neutrality (LDN); sustainable land management (SLM); integrated land use plan



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## 1. Introduction

In recent times, the pace of land use and land cover change (LULCC) has altered the environment in such a way that the resilience and sustainability of social–ecological systems is affecting the functioning of ecosystem services and causing tremendous shifts in land use [1]. Therefore, LULCCs have increased socioecological interactions and impacts, including land degradation. Land degradation is defined as a persistent reduction in land productivity because of several factors from which the land does not recover without

appropriate interventions [2], which is increasingly becoming a major global environmental problem [3,4]. Global estimates show that about 1.5 billion people are affected by land degradation, most of whom are poor rural dwellers in developing countries [5–7]. An integrated socioecological system approach to analyse land helps in understanding how changes affect ecosystem functioning, identifying synergies and trade-offs [8], and selecting appropriate sustainable land management (SLM) practices to monitor, avoid, reduce, and reverse land degradation.

In South Africa, land degradation is a serious problem affecting rural communities and their livelihoods [9–11]. While biophysical factors influence land use potential, socioeconomic factors (i.e., institutional policies and governance) influence land demand and management [12]. Historical inequality and institutional policies on access to natural resources and land in South Africa have accelerated land degradation. Almost 60% of land is degraded. with 91% of the 60% subjected to desertification [13,14]. During apartheid, almost 3.5 million people were forced to resettle in homeland territories [14]. This resulted in high and concentrated densities of people and livestock, which put pressure on the environment and degraded communal grazing areas [15,16].

The social–ecological system (SES) is a framework applied to reflect human interactions with the ecosystem and how they affect each other [10,17]. Drive Pressure State Impact Response (DPSIR) is an analytical SES framework adopted by the United Nations Environmental Programme (UNEP) and widely applied in environmental research studies across Europe [18–20]. The framework structures and organises indicators to reflect the cause–effect linkages between an ecosystem and society, and to facilitate decision making [21]. However, one of the major shortcomings of DPSIR is differentiating impacts from the state. This suggests that there is an ecosystem's natural state, and impacts include deviation from that state [22]. Another weakness of the DPSIR is that it overlooks stressors, which are crucial components of the system, and thus fails to account for the relationship between the causes and their effects on the environment [22].

The DPSIR framework was modified into the Drivers–Pressure–Stressors–Condition–Responses ($DPSCR_4$) framework, where impact was transformed into condition, with condition reflecting the state of the environment. The $DPSCR_4$ framework was adapted to include four types of responses: stressor source reduction, existing stressor remediation, ecology restoration, and ecology recovery [10,22]. The $DPSCR_4$ model defines 'drivers' as the human and natural forces driving land degradation. These drivers then exert 'pressure' on the environment that, in turn, causes chemical, physical, or biological 'stressors' [23]. The drivers, pressures, and state affect the 'condition' of the ecological structure and processes that affect the social–ecological system [23]. Management actions can feed back to the system through four types of responses, i.e., social and ecological, to achieve land degradation neutrality (LDN).

Although the DPSIR is widely used in Europe, it has seldom been used in developing countries such as South Africa, and the $DPSCR_4$ has also not been used in many studies. Therefore, a deeper understanding of the land degradation SES and responses to it is key in achieving LDN and improving livelihoods in rural areas. Moreover, the relationship between anthropogenic pressures and environmental indicators, and the existence of complex linkages between them are not well-documented in rural South Africa. Therefore, it is important to better understand the causal relationship, processes, and complex linkages between a wide range of anthropogenic activities and their impacts on the environment.

This study aims to analyse the drivers of land degradation using a SES approach to propose responses to achieve LDN by assessing land degradation using a system's application of the $DPSCR_4$ and LDN frameworks to identify the drivers of land degradation and propose SLM interventions. This study provides an innovative and coherent method to determine the drivers of land degradation in semiarid regions by identifying cause–effect relationships of variables in a system. This is particularly relevant in rural South Africa, where a dual land administration system, the traditional (tribal) and the modern (legalised) land use systems [24] prevail. This dual land use administration system has resulted in

prevalent degradation in communal areas under traditional leadership. This applies to predominantly rural districts across South Africa, and this research contributes by addressing the challenges observed in rural communal districts using a systems approach that combines drivers and management interventions from both the modern (legalised) and the traditional land use systems, and users could provide a shared way of addressing a complex land degradation issue. The case study and approach add value to the South African context to understand the drivers of land degradation by integrating transdisciplinary perspectives to identify leverage points for appropriate land management interventions.

## 2. Materials and Methods

### *2.1. Study Area*

The Greater Sekhukhune District Municipality (GSDM), the study area, is located in the northern part of South Africa in Limpopo province at 24°5′10″ S, 25°21′27″ S and 29°3′40″ E, 30°44′30″ E (Figure 1). The district consists of four local municipalities covering a total area of about 1,352,800 hectares. The total population was 1,169,762 in the 2016 census, the majority of whom live in rural areas on communal land [25].

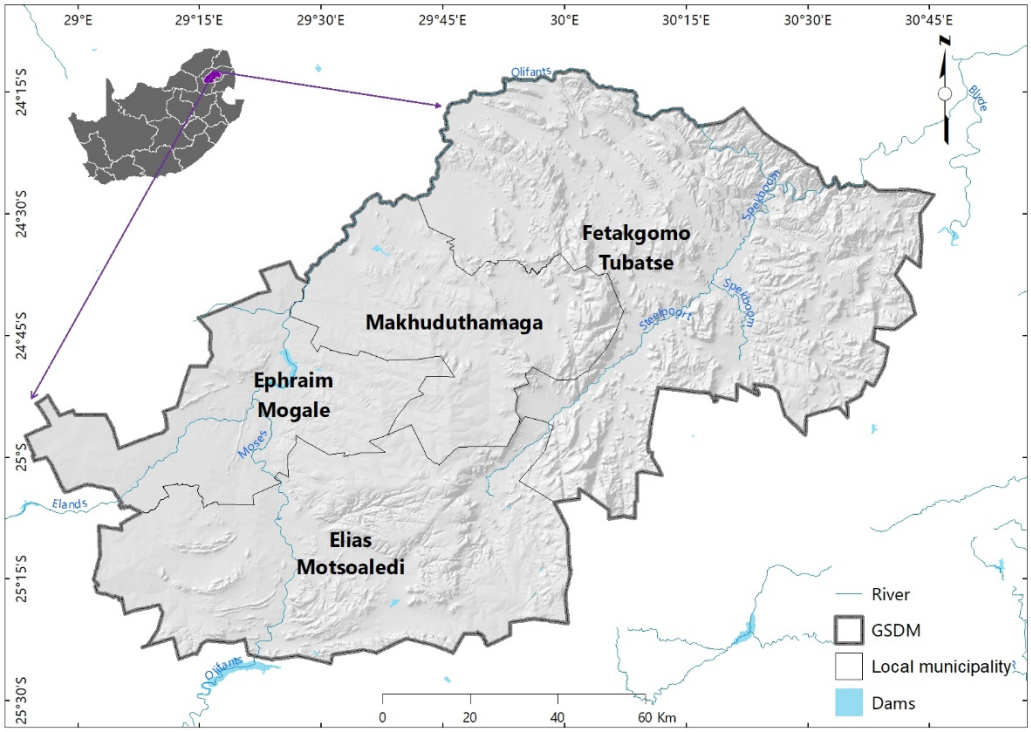


**Figure 1.** Greater Sekhukhune District Municipality (GSDM) and its four local municipalities.

The district is located in a semiarid region with an annual rainfall of about 560 mm and summer temperatures of about 23 °C [26]. The geology consists mainly of ultramafic substrates (i.e., serpentine soils) of the Rustenburg layer [27]. These soils are nutrient-deficient, characterised by heavy metals (e.g., cadmium, zinc, and nickel) that are prone to erosion [27]. The topography is undulating and lies at an altitude of about 494 m above sea level [28]. High fynbos, bushveld, natural grassland thicket, and bush clump land covers dominate the district. Unrestricted access to communal grazing and the absence of fences in the fields increase land degradation because of the low herbaceous basal cover [13,29].

### *2.2. Methodology*

The approach of this study focuses on environmental management using a system analysis framework in which the contrasting modern and traditional land use administration systems govern land use and distribution. The $DPCR_4$ framework derived from Har-

well [22] was used in this study to systematically develop a dynamic model and decision support tool to understand a socioecological system's structure across various disciplines in a rural semiarid setting. The complex patterns and processes of socioecological events were modelled, and relationships were linked to important feedback loops using the systems thinking approach [30].

### *2.3. Data Collection*

#### 2.3.1. Key Informant Interviews

For data collection, interviews were conducted with key informants selected for their extensive experience and knowledge of the GSDM [31]. A nonprobability sampling method was used to identify informants; key informants were recruited by other key informants to become part of the sample (snowball method). In this case, an official from the Limpopo Department of Agriculture and Rural Development (LDARD) based in the GSDM identified other key informants who had more than seven years of experience in natural resource use and management (e.g., for grazing, cropping, and fuelwood). The key interviewed informants were natural resource, crop and animal production managers, and performed extension services in each of the four local municipalities of the district.

Eleven key informants from the LDARD based in GSDM were individually interviewed to understand the modern land management system (Table 1). A semistructured questionnaire was used to collect information to identify the key factors of the system and its linkages (Table A1). The key informant interviews aimed to provide perspectives on important land-management-related issues in the district, and to identify progress and gaps in addressing land degradation issues.

**Table 1.** Key informants interviewed in GSDM per local municipality and years of experience working in the municipality and field.

| Local Municipality | Key Informant | Field of Expertise | Years of Experience |
|---|---|---|---|
| Fetakgomo Tubatse | 1 | Extension services | 40 |
| | 2 | Natural resource management | 13 |
| | 3 | Natural resource management | 14 |
| | 4 | Natural resource management | 12 |
| | 5 | Crop production | 14 |
| Makhuduthamaga | 6 | Natural resource management | 12 |
| | 7 | Crop production | 24 |
| Elias Motsoaledi | 8 | Animal production | 10 |
| Ephraim Mogale | 9 | Extension services | 7 |
| | 10 | Extension services | 15 |
| | 11 | Animal production | 12 |

#### 2.3.2. Focus Group Discussion with Local Pastoralists

A group discussion was held with a group of 15 local pastoralists in Mphanama village as natural resource users. The aim of the discussion was to obtain more information on historical and current pastoral conditions, the impact of degradation on pastoral capacity, livelihoods, and adaptation mechanisms. Some questions were related to how they were organised as a group, and what the rules for governance and grazing management were from their perspectives.

#### 2.3.3. Discussions with Traditional Authorities

Traditional authorities are custodians of almost half of the land (48%) in the GSDM [32]. Informal group discussions were held with 17 traditional authorities in the Fetakgomo Tubatse and Makhuduthamaga municipalities under the traditional system. The aim of the discussions was to find out the views and experiences of the traditional authorities in relation to land use and land degradation. The discussions covered the state of the land and

natural resources, land degradation, its causes, and measures to address land degradation in the area, including land use and users, and rules for land use.

### *2.4. System Dynamics and Systems Dynamic Modelling: DPSCR$_4$ Model*

The system dynamics approach helps in clearly representing, analysing, and understanding complex systems. The triangulation of key informant interviews, discussions with local pastoralists and traditional authorities, and the scientific literature formed the basis for the application of the DPCSR$_4$ and systematic analysis to understand land degradation in the GSDM. Figure 2 shows a systemic overview of expert knowledge on the DPSCR$_4$ framework for addressing land degradation using an adapted SES approach [10]. The DPSCR$_4$ components are each described as follows:

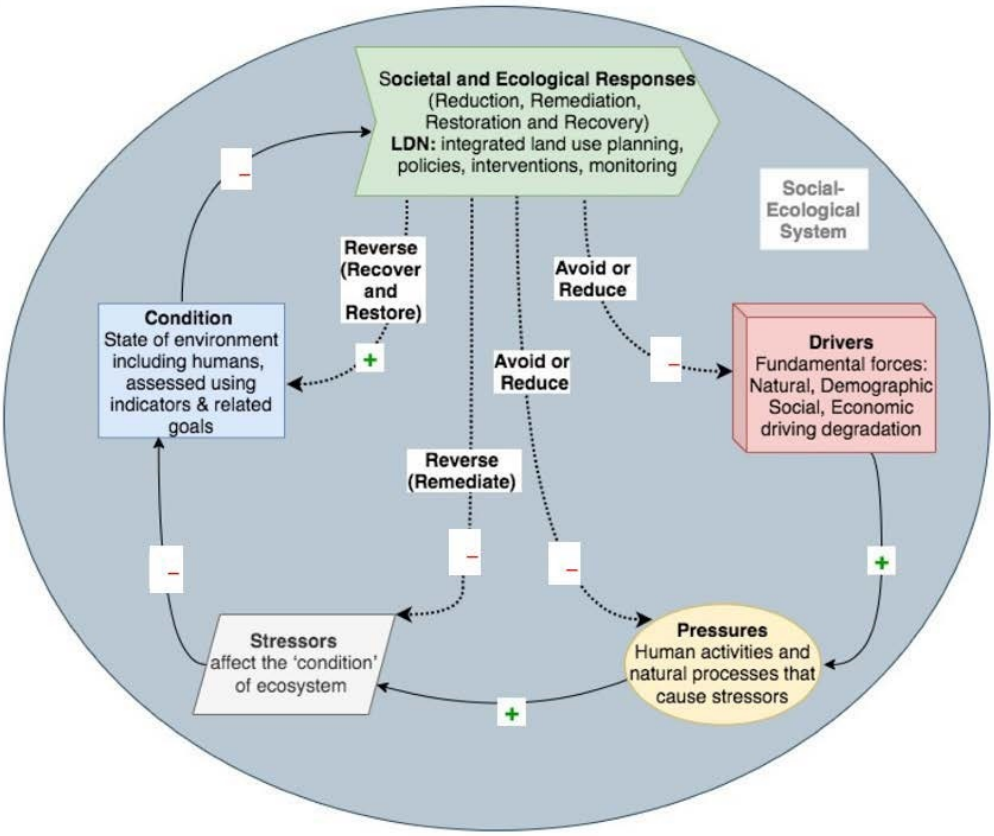


**Figure 2.** DPSCR$_4$ framework to combat land degradation using an SES approach relationship, adapted from Itzkin [10].

#### 2.4.1. Drivers

Drivers of land degradation are factors that can cause changes in the socioecological system or lead to changes in behaviour. Several studies cite demographic, institutional, economic, political, technological development, and sociocultural factors as drivers of environmental changes affecting the socioecological system [33]. These drivers can be natural, anthropogenic, or both, and direct and indirect factors can be distinguished.

#### 2.4.2. Pressures

As defined by [34], a pressure is the result of human activities and natural drivers that directly affect the ecosystem and alter the natural environment. Unsustainable human activities exacerbated by natural disturbances, such as recurrent droughts or variable rainfall variability i.e., flash floods, lead to land degradation and desertification [22].

#### 2.4.3. Stressors

Stressors occur due to pressures faced by the ecosystem and can be chemical, physical, or biological factors that affect the state of the environment [22]. Stressors are represented by a set of descriptors of system attributes and are the result of a relationship between cause and effect due to stresses at a particular place and time, or due to factors that may be new to the system, such as toxic chemicals [22,34].

#### 2.4.4. Conditions

The conditions of the system are described by different groups of system attributes that are influenced by pressures and stressors, and explained by the type, degree, and rate of land degradation at a given time. The descriptor used in the study was vegetation, i.e., seasonal NDVI, to assess the extent and rate of land degradation [23].

The NDVI change was calculated to assess whether the condition of the environment was degrading and to show the extent of the total affected area [35]. The NDVI was obtained using Landsat [6–8] images (30 m resolution) from 1990 to 2019 on a five-year interval, and processed with ERDAS Imagine 2018 software.

#### 2.4.5. Responses

This framework takes an integrated approach that avoids and reduces potential land degradation, and reverses the existing land degradation [36]. The $DPSCR_4$ framework prescribes three global (biophysical) indicators of ecosystem services: LULCC, land productivity (NDVI), and carbon stocks [36]. Itzkin [10] applied several features that made LDN suitable for her case study and applicable in this study. These include the explicit focus on the SES approach, local-level implementation, the ease of adaptation to $DPSCR_4$ (previously applied to DPSIR), and the participatory integrated land use plan to achieve LDN (Figure 2).

The LDN framework was adapted into the $DPSCR_4$ framework, with the green '+' signs representing a same-direction causal effect relationship, and the red '−' signs representing the opposite relationship [10].

## 3. Results

The results from the assessment of land degradation in the GSDM are presented in two subsections. The first section presents the results of key informant interviews and focus group discussions with local pastoralists articulating the drivers of LULCC and land degradation. The second section analyses the findings of the $DRSCR_4$ that describe and present system attributes to better understand the interconnectedness of social and environmental factors driving land degradation in the ecosystem for achieving SLM.

### *3.1. Drivers of Land Degradation: Identified LULCCs That Lead to Land Degradation from-+ Interviews, Traditional Authority Perspectives, and Local Pastoralist Views*

The LULCC is the result of cumulative, inter-related factors among socioeconomic, institutional, demographic, and biophysical drivers [35]. The results of key informant interviews on the LULCC that contributed to land degradation in the Greater Sekhukhune District are summarised below (Table 2).

Key informant interviews and discussions with local pastoralists revealed that several factors are the main drivers of LULCC contributing to land degradation. The main drivers are inappropriate grazing management systems/overgrazing, governance issues, inappropriate soil management, deforestation, the removal of natural vegetation, settlement encroachment on cropland, and soil erosion. If the traditional and modern systems had an integrated and coordinated system, such as land use plans and knowledge sharing, such as indigenous knowledge from the traditional system and technical knowledge from the modern system, land degradation could be reduced and avoided.

**Table 2.** Drivers of degradation in the GDSM as perceived by key informants of the Limpopo Department of Agriculture and Rural Development (LDARD) (*N* = 11).

| Drivers of Land Degradation in the GDSM | Number of Mentions |
|---|---|
| Overgrazing/grazing management: poor agricultural practices and rangeland management. | 11 |
| Physical factors (steep terrain, erodible soils). | 2 |
| Cropland abandonment. | 9 |
| Soil erosion. | 10 |
| Unplanned settlement/settlement encroachment into cropping land. | 10 |
| Governance issues: local, social and cultural rules and regulations that affect resource access. | 11 |
| Extreme weather (droughts, storms) and climate. | 6 |
| Inputs and infrastructure (roads, markets, co-operatives, fencing to manage animal movement, etc.). | 10 |
| Alien invasive species. | 6 |
| Climate change. | 9 |
| Poverty and disempowerment. | 7 |
| Historical, sociopolitical factors. | 3 |
| Deforestation and the removal of natural vegetation. | 11 |
| Land tenure. | 7 |
| Population pressure. | 8 |
| Inappropriate soil management. | 11 |
| Disturbance of hydrological regimes (improper surfaces and groundwater recharge). | 10 |
| Sand mining. | 7 |
| Veld fires. | 2 |

The discussions with traditional authorities on the prospects and experiences of land degradation and its drivers indicated that rainfall is declining and droughts are increasing, leading to shrinking wetlands and water scarcity. Water sources such as rivers and dams are silted up due to sand mining and soil erosion. Settlement encroachments into arable and range lands have also increased. The increase in human and livestock populations has put pressure on rangelands; because of poverty, pastoralists lack additional livestock feed such as crop residues. This has led to overgrazing, causing gullies, bush encroachment, and alien invasive species.

The traditional authorities indicated that farming had declined and cropping lands had been abandoned. Traditional farming methods that are not resource-efficient reduce soil fertility, and damages the environment and natural resources. There is a lack of information on appropriate farming techniques such as water conversation, water-smart agriculture, climate-smart agriculture, soil conservation, and securing water for livestock. Factors contributing to the decline in crop production include a decrease in rainfall, poor livestock management, a lack of cropland fencing, birds, damage to crops by livestock, and the consequent abandonment of cropland. Livestock management is a major challenge, as livestock move onto croplands, leading to cropland abandonment; pastoralists do not round up their livestock during the cropping season.

Tribal councils have also lost control over land use, as they fail to control the residents who change land use without informing them. Activities such as illegal sand mining have increased due to declining agricultural productivity. This has exacerbated the formation of gullies in the area and is destroying croplands. The lack of rangeland management has also intensified, as the tribal council does not apply any grazing management and stocking rate controls, which further increases the pace of vegetation loss and degradation. Solutions include planting trees, checking dams, gabions, and planting aloes as vegetative barriers.

### *3.2. Systemic Analysis Results (DPSCR$_4$ Framework)*

The identified factors contributing to land degradation during the interviews and discussion were framed in terms of DPSCR$_4$, with relative impacts specific to the scale of

the study area. The $DPSCR_4$ from Table 3 was arranged into two system diagrams, namely, drivers, pressures, and stressors that degrade the land (Figure 3), and integrated land use planning to achieve LDN and improve sustainable livelihoods in the Greater Sekhukhune District Municipality.

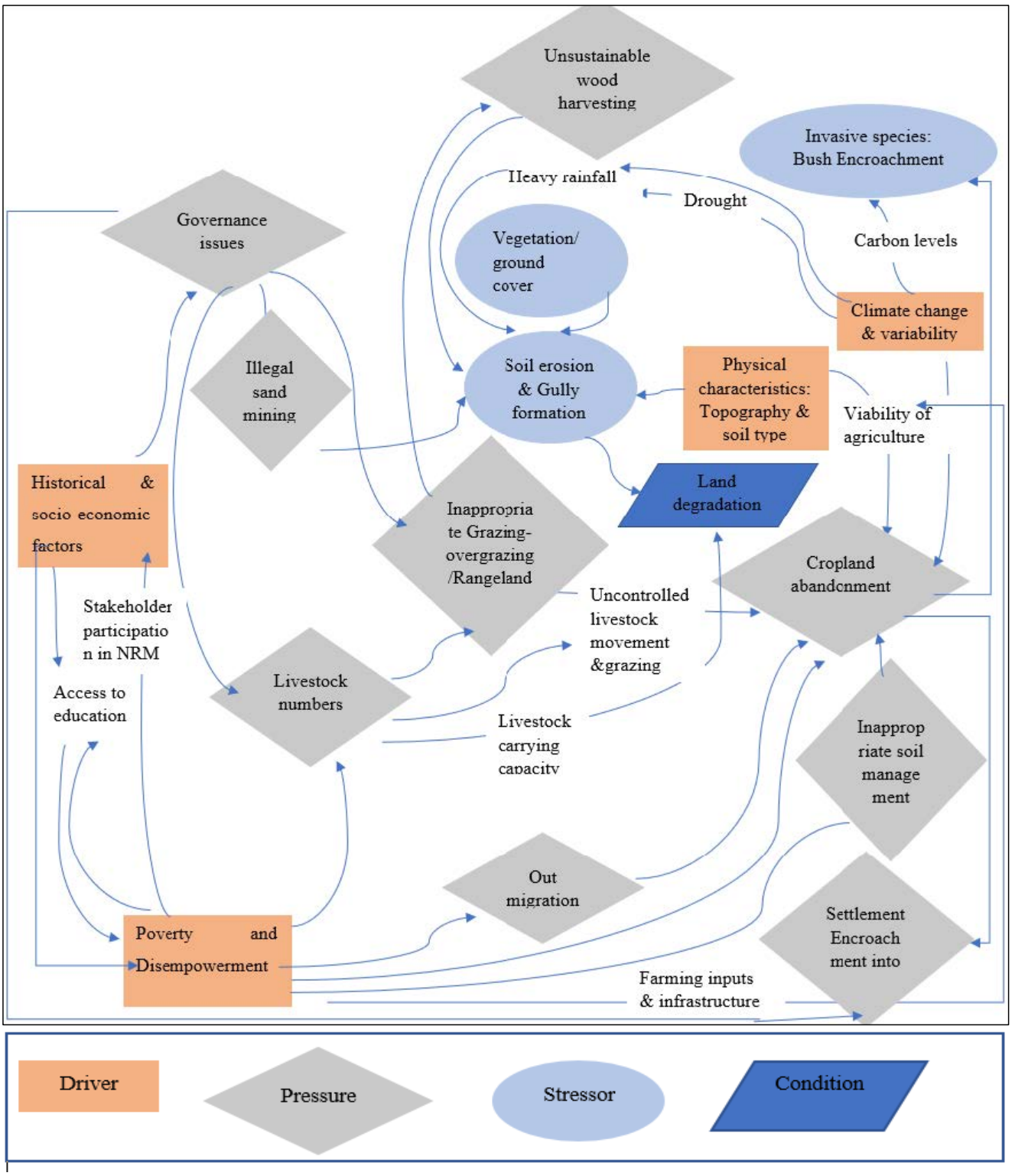


**Figure 3.** Drivers, pressures, stressors, and condition of the ecosystem in GSDM.

**Table 3.** $DPSCR_4$ in the GSDM.

| Drivers | Pressures | Stressors | Condition | Responses |
| --- | --- | --- | --- | --- |
| Natural drivers: soil type topography, climate variability, and extreme weather. | Cropland Abandonment. | Invasive species: mostly bush encroachment. | Goal: address land degradation. | Reduction: land-use management (appointing rangers), environmental education, and market access initiatives. Local rules and regulations |
| Human-induced: historical and socio-political factors, and land tenure | Governance issues, unplanned settlement/settlement encroachment into cropping land, population pressure including livestock numbers, and unsustainable wood harvesting. | Low vegetation cover | Goal: promoting sustainable livelihoods | Restoration: rehabilitate eroded land, home garden agroforestry, and removing invasive species |
| Poverty and disempowerment | Grazing management/overgrazing: inappropriate crop and rangeland, and soil management. | Gully formation | Goal: poverty alleviation through empowerment and improving capacity. | Recovery: resting landscape to enable ecological recovery. |
| Population pressure and climate change | Outmigration and illegal sand mining | Soil erosion | | All four responses: LDN-integrated land use planning |

#### 3.2.1. Pressure

Past and present policies have led to unstable governance. Traditional authorities are custodians of natural resources; however, poverty and disenfranchisement reduce participation in natural resource management and exacerbate governance problems. Governance issues in the district have enabled free-roaming livestock, overstocking, unsustainable wood harvesting in rangeland (abandoned crop fields are currently grazing fields) and the encroachment of settlements into cropland/productive land. Disenfranchisement, poverty, and natural drivers also hinder farmers from acquiring inputs, which affects the success of agriculture and further drives the abandonment of croplands.

The spread of settlements in the district is due to population pressure and the availability of land. The main problem that emerged from the key informants' interviews was the settlement encroachment on arable land. As indicated by the traditional authorities and key informants, there is no strict demarcation of settlements, cropland, and rangeland in the district. It was also highlighted that the traditional authorities reallocate arable land that has been abandoned for more than ten years for settlement, as per their rules.

Governance issues have led to an increase in illegal sand mining in the GSDM. Sand mining is driven by population growth, the construction industry, and development needs [37]. Traditional authorities emphasised that local people have begun sand mining to earn a living as agricultural production has declined. Most sand-mining activities are illegal, localised, and have direct and indirect impacts on the hydromorphology of the river/lake/wetland ecosystems and human health [37]. Sand extraction has a negative impact on groundwater recharge, affects aquifers, increases sedimentation, and contributes to gully formation and land degradation [37].

3.2.2. Stressors

Extreme weather events, i.e., heavy rainfall and prolonged droughts, low vegetation/ground cover due to droughts and overgrazing, unsustainable wood harvesting, and sand mining, have led to soil erosion and gully formations throughout the district. Rainfall variability and high flow velocity due to topography have lowered the bed, contributing to the bank erosion of water sources and general sedimentation load.

As cropland abandonment increases, invasive species extend their distribution on abandoned cropland and degrade the landscape, which in turn reduces the agricultural viability of agriculture and grazing capacity, leading to further cropland abandonment, and the loss of livestock and livelihoods in a reinforcing cycle.

The expansion of invasive plant species was further stimulated by rising carbon levels in the atmosphere as a result of climate change [38]. Therefore, bush encroachment into rangelands is observed throughout the district, and natural vegetation/grassland cover is decreasing.

The topography, frequent and prolonged droughts that reduce vegetation cover, and rainfall variability and intensity have increased flow velocity and sediment flux in the Lepellane Dam, located between the villages of Mphanama and Ga-Radingwana in the Greater Tubatse/Fetakgomo Tubatse Local Municipality. The Lepellane Dam is fully silted because of soil erosion and the lack of conservation measures in the catchment. This affected and reduced the water quality and quantity downstream of Lepellane River, particularly after 2014, and similar observations were highlighted by the herders [39].

3.2.3. Condition

Five-year interval NDVI change trend results for the wet and dry seasons, obtained from 1990 to 2019, are presented in Figure 4. There is an increasing negative NDVI change in both seasons, with a steeper trend in the dry season. This shows that the productivity of the area declined in general and experienced extreme decline between 2010 and 2015 during both the wet and dry seasons, with the highest negative NDVI changes of 96.39% and 97.05%, respectively. This confirmed the information given by pastoralists about the increasing deterioration of Lepellane River during this period.

(**a**)

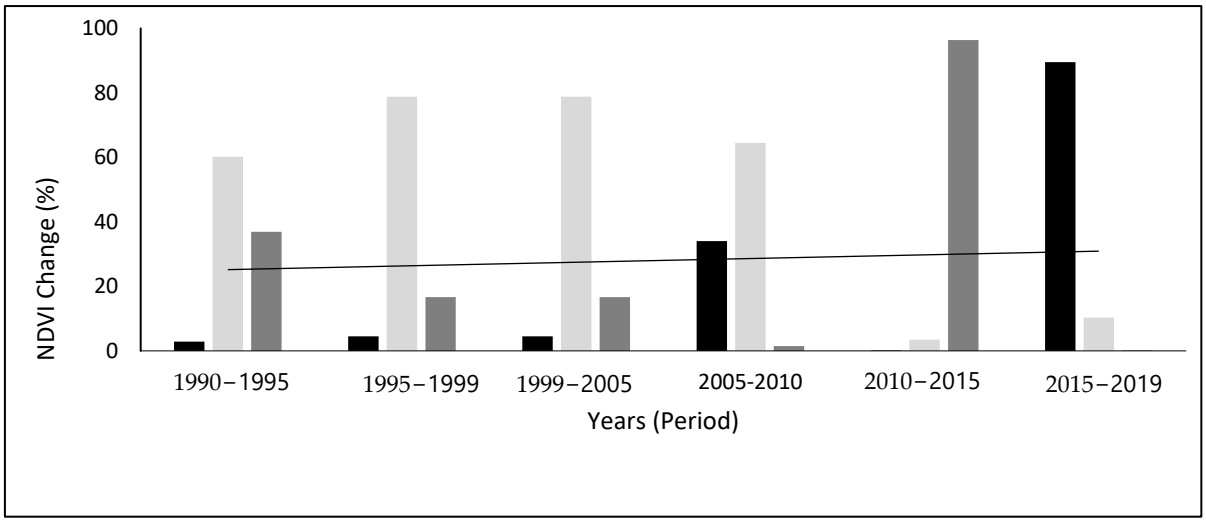


**Figure 4.** *Cont.*

(**b**)

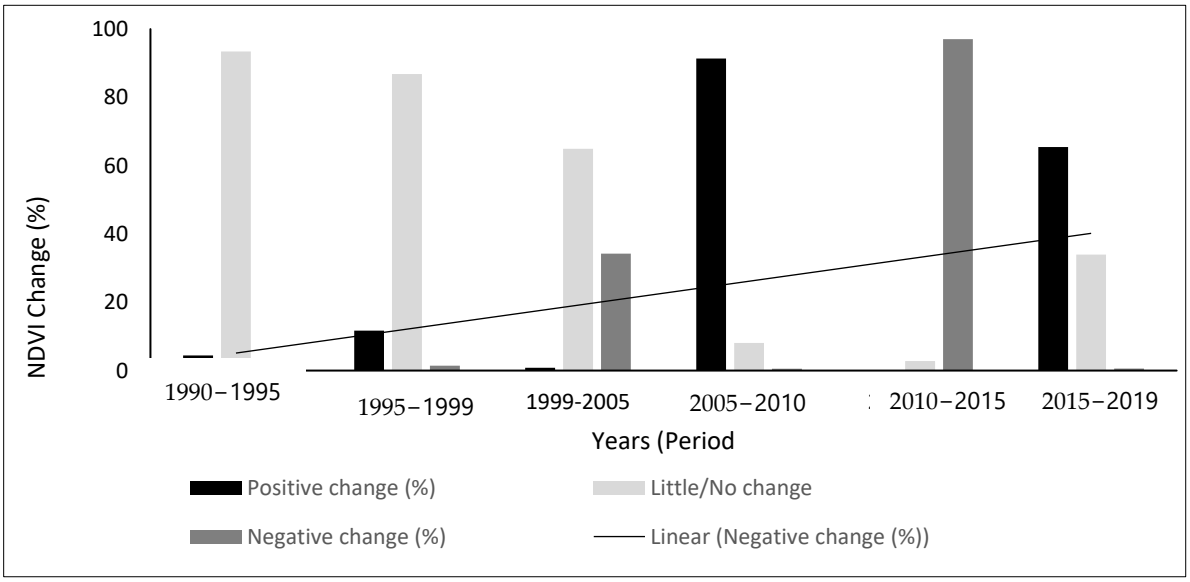


**Figure 4.** Negative NDVI change trend of (**a**) wet and (**b**) dry seasons from 1990 to 2019.

3.2.4. Response to Reduce, Remediate, Restore, and Recover Degraded Land in the GSDM

The relationships among drivers, pressures, stressors, conditions, and the four responses are illustrated in Figure 5. A comprehensive analysis of the individual factors and potential responses provides alternative potential feedback loops, and the analysis can be used as a basis for integrated land use planning. Responses to land degradation show suggestions from key informants, as well as the workshops feedback from the tribal council and local pastoralists for reducing stress sources, remediating existing stressors, and restoring and recovering the ecology.

The dynamic approaches to the implementation of response actions aim at mitigating drivers, pressures, and stressors on the landscape. Environmental education is the most important measure that increases community engagement in natural resource management. Key informants mentioned that a junior land care programme was recently introduced to sensitise and encourage school children to manage natural resources. A participating school adopts a natural resource such as a river, and awards are given to encourage care and maintenance. This is very important for sustainability, as children develop awareness and change their behaviour in the community. Another important factor is improving market access, which enables livestock keepers to improve and maintain livestock quality while reducing their numbers. Moreover, policies and regulations need to purposefully address the negative impacts of previous and current policies on the social and environmental conditions of the district. Key informants mentioned that a ranger system policy should be reintroduced in the district as it was prior to 1994, when rangers were deployed to ensure that communities used resources sustainably and practiced a rotational grazing system.

One of the interventions applied in response to land degradation in the area is the eradication of alien invasive species, which directly reduces the populations of invasive species and bush encroachment on the landscape. Other measures that reduce bush encroachment and rehabilitate the rangeland are brush packing, reseeded half-moons, and selective bush thinning which is currently applied in the Mphanama village grazing land rehabilitation programme (Figure 6). These methods should be upscaled and applied to the degraded parts of the district. Given that more than 50% of the district is covered by rangeland, overgrazing can be reduced and stopped, and the degradation trend reversed through a well-designed veld management system.

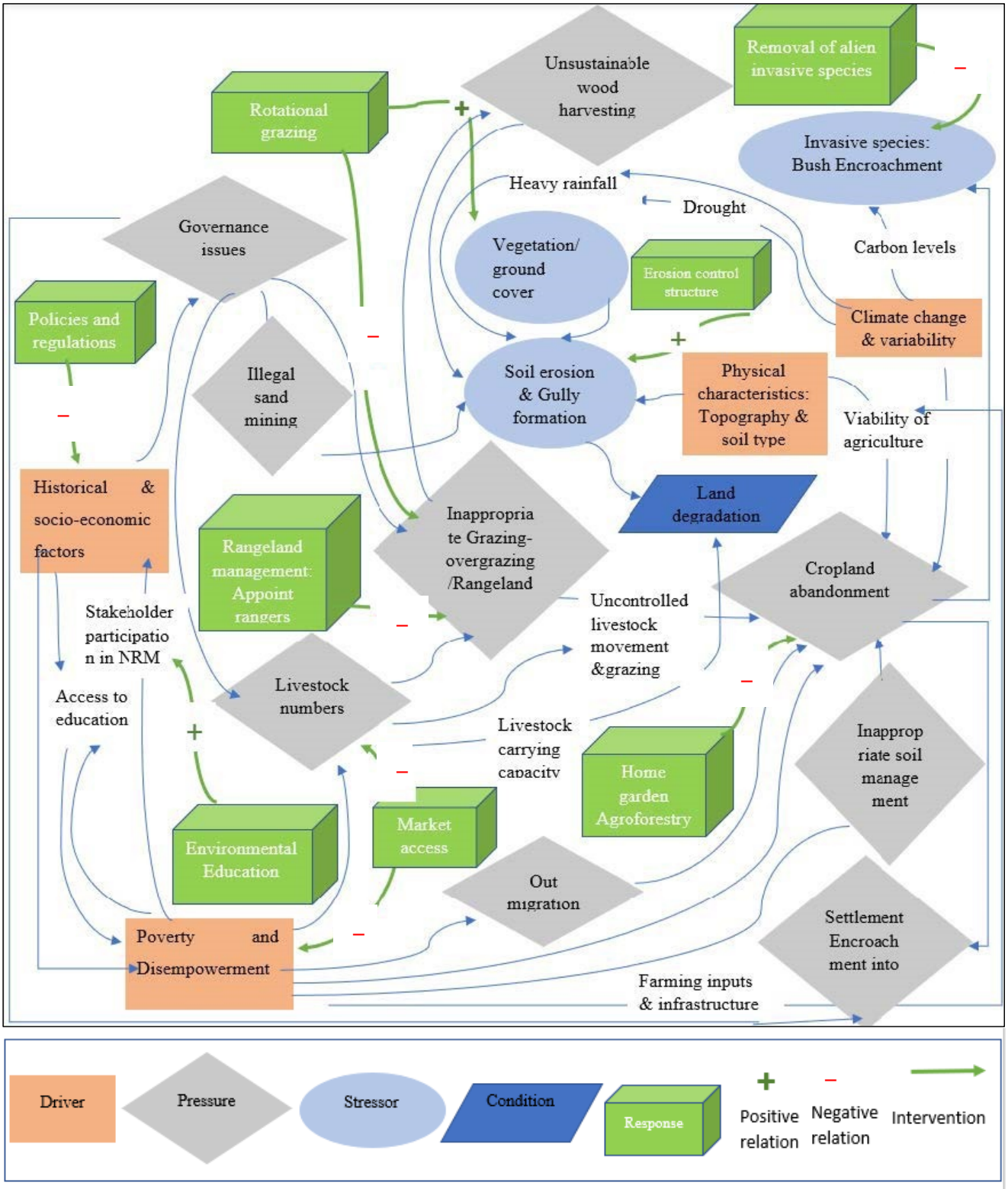


**Figure 5.** Integrated land use planning to avoid, reduce, and reverse land degradation, and improve sustainable livelihoods in GSDM.

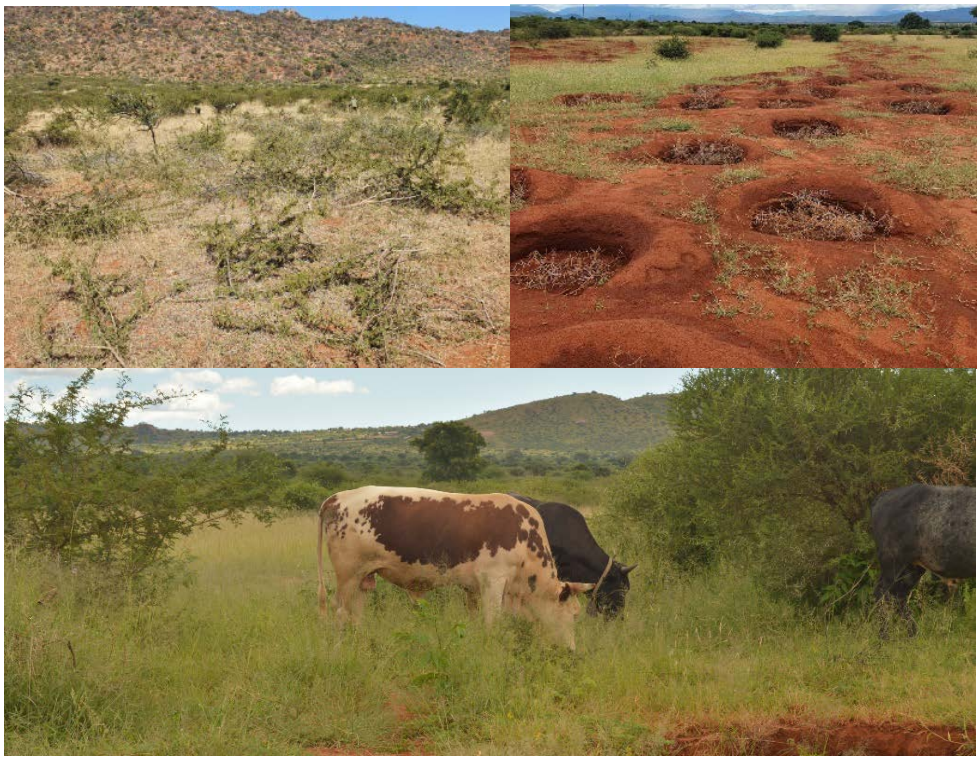

**Figure 6.** Land rehabilitation of the Mphanama rangeland under the UNDP GEF5 SLM project. (left to right) Brush packing and ponding to increase the vegetative recruitment and the survival rate of regenerating plants and of seeded grass.

Home-garden agroforestry should be encouraged throughout the district while livestock roam uncontrolled and cropland is not fenced. This would increase vegetation cover within the settlements, improve livelihoods, and create microclimates.

Although erosion control structures suitable for the site and context were identified, key informants mentioned that the vandalism of erosion control structures and fences to control animal movement hinders land rehabilitation. Most of the erosion control structures erected by previous initiatives were toppled by flash floods, never maintained, or vandalised. Therefore, it was suggested in the discussions to form informal institutions with communities that have social and cultural arrangements, local rules, and obligations that influence access to and management of resources.

Land use planning integrated with LDN can prevent, reduce, and reverse land degradation in several ways. These include the coordination and transparency of land use plans through workshops (highlighted in key informant interviews) among traditional authorities, local government, natural-resource management, and the community. This will further promote stakeholder participation in natural-resource management. The Department of Forestry, Fisheries, and the Environment has made significant efforts and invested in rehabilitation by erecting soil erosion control structures. In rehabilitation, it is important for community members and traditional authorities to be engaged from the onset to incorporate traditional knowledge and own the process.

## 4. Discussion

The application of a $DPSCR_4$ SES highlights how land degradation results from a set of inter-related social and biophysical factors [40,41] $DPSCR_4$ system analysis raises awareness and offers a compressive analysis of drivers, pressures, stressors, conditions, and responses to capture mechanisms that influence the ecosystem and the causes of land degradation. The results show how complex land degradation phenomena can be addressed within the framework of two contrasting land use management systems.

### *4.1. Drivers, Pressure, Stressors, and Condition of Land Degradation in the GSDM*

The analysis of the $DPSCR_4$ system revealed that natural drivers such as dispersive duplex soils, and climate extremes such as prolonged droughts and high rainfall intensity predisposed the district to soil erosion and gully formation (stressors). The district experiences recurrent periods of droughts and high rainfall intensity, resulting in a highly variable climate that affects productivity [42] Climate variability caused soil erosion and gully formation in the district, such that when drought events reduce vegetation cover, high-intensity rainfall would detach soil particles (dispersive soil noted by [26] in areas of low vegetation cover, causing soil erosion and gullies [43]. The literature has also reported rainfall variability, climate change, soil erodibility, and low vegetation cover as natural drivers of land degradation [10,16,38,44].

The findings are also in line with [45], in that the interplay between natural and anthropogenic factors is exacerbating land degradation in the district. The past and present policies of the land that led to the ripple-down effects of anthropogenic factors that degraded the land, as noted by Hoffman and Todd [15], and Meadows and Hoffman [16], have led to soil erosion and gully formation due to the high population density, the subsequent cropland abandonment, and the lack of grazing management. These factors are part of the socioeconomic drivers that lead to poverty and the lack or absence of governance, causing widespread erosion and land degradation.

Human activities, such as unrestricted access to communal rangeland, a lack of fencing around fields, and cropland abandonment, increase land degradation because of the low herbaceous basal cover [13,29]. These findings are similar to those of Itzkin and others [10], and Kakembo and Rowntree [46], in the Eastern Cape province and other former homelands that face similar socioecological challenges and landscape change conditions. These studies also found that dispersive soils associated with overgrazing and cropland abandonment were due to poor governance and poverty. Rural subsistence farming used to dominate land use in communal areas [23]; in the district, croplands are currently almost entirely abandoned and used for grazing due to a lack of rainfall, reduced soil fertility, uncontrollable livestock movement, the vandalism of fences, and income dependency on social grants. Mpandeli and others [42] found that smallholder farmers in the district find it difficult to achieve high crop yields because of the low and unreliable rainfall; hence, croplands are abandoned [29,42,47]. Therefore, various inter-related socioecological challenges have led to changes in the environmental conditions of communal rangeland that continue to degrade the landscape.

This study also showed that poverty and disempowerment lead to poor natural-resource management, i.e., unsustainable land practices and land tenure conflicts. In the district, some unsustainable land use practices resulting from poor governance are wood harvesting, uncontrolled livestock movement, overgrazing, overstocking, and illegal sand mining. After 1994, the opposing forms of modern systems and traditional forms of governance have been an on-going source of tension because of the overlapping roles and responsibilities [10].

### *4.2. Towards Achieving Land Degradation Neutrality: The Integration of the $DPSCR_4$ and LDN Frameworks*

The integration of the $DPSCR_4$ and LDN frameworks allows for a focused and clear analysis of LULCCs that contribute to land degradation and intervention points [10]. A land degradation response was applied using the LDN framework in the GSDM to prevent, reduce, and reverse land degradation [35]. The framework was introduced to promote effective policies for SLM practices by preventing and reducing land degradation, and enhancing land-based natural capital through rehabilitation in the district [48].

Overgrazing and uncontrolled livestock are the main drivers of land degradation in the district. Key informants emphasised that a ranger system that regulates transhumant grazing that is developed by the community would enforce the sustainable use of resources. This would be achieved with the support of traditional authorities, LDARD officials, and

researchers who would monitor, advise on, or restrict activities that trigger or increase erosion. Interventions require a guide for the application of various measures based on biophysical assessment data, participatory mapping involving the community, and the identification of areas at low or high risk of degradation [49,50].

These interventions could be integrated in a village-level land use plan to address land degradation in the district. Land degradation is affecting the livelihoods of rural communities in the GSDM and all across South Africa. Therefore, through the application of the $DPSCR_4$ framework, an integrated social and ecological study provides clear policy planning, and changes in land use and management to achieve LDN goals.

## 5. Conclusions

Land degradation and the lack of integrated natural-resource planning threaten the livelihoods of vulnerable rural communities in South Africa. Poverty and disenfranchisement in rural areas, and a dependence on natural resources are the main human drivers that lead to various linkages causing pressure and stress to the landscape. Natural factors, such as climatic variability i.e., frequent, prolonged drought events and intense rainfall, in the district and semiarid regions expose these landscapes to severe land degradation, which is exacerbated by human activities. This study demonstrated the synergistic impact of land degradation due to the interaction between various socioeconomic factors and natural drivers. We found that the challenges and conflicts between the two systems of land use management can be addressed with an LDN using an integrated management system. We propose that LDN could be achieved through a coordinated plan between the two systems, where the traditional authorities' duties would reflect more insight into communicating and connecting with the community and its values, while the modern system could support traditional authorities with technical expertise (LDN) in the study area and other rural semiarid regions. The proposed SLM interventions for the study are rangeland management, the eradication of alien invasion species, environmental education, the revision of policies and regulation, local rules enforced by the community and tribal authorities, capacitating tribal authorities, and extension officers. Land use problems highlighted by both the traditional and the modern system, such as illegal sand mining, uncontrollable livestock grazing, and the vandalism of erosion control structures or fences, are challenges that traditional authorities could solve with the community if they establish local rules and form associations to enforce these rules. The study is of critical benefit to South Africa and other developing countries that are experiencing inequities in resource allocation, describing steps to reverse and rehabilitate highly altered landscapes. Therefore, an integrated SES assessment provides an understanding and basis for mutual beneficial land use management plans to improve landscape conditions and sustain livelihoods in the GSDM.

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## Appendix A

**Table A1.** Key informant Semi-structured interview Questionnaire.

| | | |
|---|---|---|
| 1. | How long have you been working in the area? In the years worked, what are the most significant changes experienced or seen in the area? (e.g., increase in gullies, soil fertility and crop yields, change in grazing species composition, invasive species, less palatable species, reduced ground water table etc.) | |
| 2. | Where did these changes occur and why in those particular locations? | |
| 3. | When did the changes occur and why then? what triggered those changes? | |
| 4. | What do you think are the (i) direct causes and (ii) in-direct causes are the main reasons for changes in LULC?<br>Direct Causes<br>Indirect | |
| 5. | Impact of changes in LULC on land degradation? Indicate where applies the causes of land degradation and specify: | |
| | **Direct Causes** | **Specify** |
| | (i) Inappropriate soil management | |
| | (ii) Poor agricultural practices and rangeland management (annual, perennial, shrub, and tree crops) | |
| | (iii) Excessive wood harvesting and removal of natural vegetation due to: | |
| | (iv) Disturbance of hydrological regimes due to: | |
| | (v) Natural factors: i.e., intensive, or extreme rainfall, climate change and change of seasonal rainfall (perception of land users) | |
| | (vi) Others | |
| | **Indirect Causes** | **Specify** |
| | (i) Population pressure | |
| | (ii) Land Tenure: Poorly defined tenure security. | |
| | (iii) Poverty: limits land-user investment and choice. use of marginal land prone to land degradation (e.g., steeply sloping areas) | |
| | (v) Labour Availability: Shortage of rural labour (e.g., through migration, out migration, ageing) leading to abandonment of traditional resource conservation practices such as terrace maintenance | |
| | (vi) Inputs and infrastructure: (roads, markets, Co-operatives, fencing to manage animal movement etc.): | |
| | (vii) Informal institutions: arrangement of local rules and regulations, affecting access to resources. | |
| | (viii) Others | |

**Table A1.** *Cont.*

| | | |
|---|---|---|
| 6. | What are the potential economic, social, and environmental impacts of LULC changes and land degradation? | |
| 7. | What is done to address these changes? What methods are used to improve soil fertility, to reduce erosion, and manage water resources? Has there been adoption of new practices? | |
| If adoption of SLM practices | | If no adoption of SLM practices |
| Are the new practices effective? | | What are the constraints for adoption e.g., insecurity of tenure, seasonal migration, land shortage, lack of capital, labour unavailability)? |
| 8. | What is the percentage of farmers using these practices? | |
| | Other | |
| 9. | Are there protected areas and why are they protected? Areas once heavily utilized may have become protected, preventing the harvesting of forest products, use for grazing. What impact has this had on the land and users' livelihoods? | |
| 10. | What mechanisms are used to control use of land such as grazing periods? | |
| | Formal regulation | Informal (customary) regulations |
| 11. | Are there any land use conflicts between the two systems? If so, what are the conflicts and how can they be harmonised, i.e., access, use, and left to land? | |

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