The Role of Ecological Infrastructure (EI) in Mitigating the Impacts of Droughts

Report to the
WATER RESEARCH COMMISSION

by

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EXECUTIVE SUMMARY

Rationale

South Africa is an arid country with a mean annual rainfall of less than 500 mm, only 9% of which ends up as water in rivers and aquifers, so every drop is scarce and it is imperative that water is optimally used. Water supplies are unevenly distributed, only 8% of the land area yields about half the runoff, and these major surface water sources need to be managed to protect the quality and quantity of the water they provide. Since most of the high yielding areas are still under natural vegetation, it is critical to ensure that these are maintained for optimal water production.

South Africa is currently experiencing a severe drought, which began in 2015, and this has resulted in crop losses, imposition of water restrictions and significant impacts on water and food security. Droughts are likely to become more intense and more frequent in the future due to changing climatic regimes; at the same time, energy, land and water demands are expected to increase globally. This has implications for associated impacts on the availability of grasses for livestock, and water and food security (due to crop losses and water availability). It is clear that South African society needs to respond more appropriately to droughts through timeous and transformative interventions, moving away from responses that do not yield long-term gains, to optimise the supply of water resources.

In the past, the normal go-to response for water security in many countries, including South Africa, has been to build dams and institute inter-basin transfers. This approach is still valid, but it should be complemented with the (long-term) approach of protection and rehabilitation of the EI that not only serves the purpose of water security, but it provides additional gains in terms of ecosystem functioning. Intact or well-managed EI provide various ecosystem services and services of purifying and supplying fresh water, and thus, they justify protection and management. The most economically and socially valuable services that we obtain from healthy catchments are those related to hydrological services, which include water filtration/purification, seasonal flow regulation, erosion and sediment control, and habitat preservation. The approaches for investing in EI are also in line with the National Water Resource Strategy (NWRS2) which promotes rehabilitating strategic water ecosystems and protecting and maintaining freshwater ecosystem priority areas.

Humans have modified catchment properties, particularly the vegetation, to provide grazing for livestock, for cultivation, and plantations for food, wood, timber and fibre and to establish settlements. These modifications are necessary to meet human needs, but typically they alter how the rainwater is partitioned, often reducing river flows or increasing the volume of floods, or both. Changes in water flows are also closely linked to sediment flows, and the reduced vegetation cover in heavily- or over-grazed lands or poorly designed cultivation may result in increases in soil erosion. Typically, this triggers a negative spiral with further, more rapid erosion, sedimentation of dams and less usable water. Thus, it is crucial for people to recognise the early stages of such degradation and alter their land-use practices to halt further damage and restore the ecosystems that protect their livelihoods.

Objectives

The main aims of the project were:

1. To explain how well-managed ecological infrastructure can help to mitigate the impacts of droughts on human livelihoods and well-being and to propose strategic responses that will maintain and enhance the value of this service that people will embrace and implement.
2. Assessment of ecological infrastructure presence, current state and prioritisation in three focal catchments.
3. To provide an assessment of how the ecological infrastructure facilitates drought mitigation.

We have interrogated these aims using four target EI land cover types in three catchments; the EI land cover types were selected primarily based on their recognition by the SANBI Framework on Investment in Ecological Infrastructure. Maintenance and restoration of these areas will support the flow regulation ecosystem services. These target EI land cover types are grasslands/rangelands, riparian zones, wetlands, and abandoned croplands. The last category has been added as previous research has identified them as focal areas for invasive alien plant invasion (see report for details), which are well known for their large water use as well as source and cause of erosion.

Land degradation is defined by the 2019 IPCC Special Report on Climate Change and Land (SRCCL) as follows: '*a negative trend in land condition, caused by direct or indirect human-induced processes including anthropogenic climate change, expressed as long-term reduction or loss of at least one of the following: biological productivity, ecological integrity or value to humans*'. Land degradation leads to loss of biodiversity and ecosystem services that are worth >10% of annual global gross domestic product according to a UN report. Therefore, ecosystem restoration complements conservation of biodiversity and it can halt degradation of natural ecosystems, help maintain and restore ecological integrity, and provision ecosystem services.

Humans derive benefits from production ecosystems like agriculture or managed forests, but at the same time this results in biodiversity loss and reduced ecosystem services, including those related to hydrologic and ecohydrologic processes. The challenge lies in balancing the benefits against the losses and this is a reason for prioritising restoration of degraded land. Land degradation assessment approaches are vital to guide and support land degradation interventions. Thus, identifying the location and the reasons behind land degradation in the landscape is the first step for designing a response strategy.

Methodology

Aim 1 of the project has investigated two sub-questions using published and grey literature primarily from South Africa but also relevant literature from across the world. These two sub-questions are how EI can mitigate the impacts of drought, and the value of EI. The value of EI is particularly noted in the context of water flow regulation ecosystem service, since water security can be improved by having healthy EI. This is presented from the point of vulnerable rural populations who are dependent on well-functioning (healthy) natural resources.

Aim 2 of the projects evaluated the extent of ecological infrastructure using various national databases in three focal catchments: White Kei, Tsitsa and Upper Crocodile. The study conducted the degradation analysis in these three focal catchments using Trends.Earth platform, which is designed to provide an assessment of the SDG15.3.1 indicator that aims "to monitor for the proportion of land that is degraded over the total land area". The SDG15.3.1 degradation indicator has three key sub-indicators, namely land productivity, land cover and soil organic carbon. These sub-indicators are surrogates for key factors and driving variables for assessing the delivery of ecosystem services, and this makes the indicator SDG15.3.1 more comprehensive in its evaluation of land degradation. The Trends.Earth plugin was developed as part of the Global Environmental Facility initiative to extend the availability and the use of global data sources to study land degradation at multiple scales. The plugin has been utilised in several locations for vegetation productivity measures and land degradation evaluations. The SDG 15.3.1 assessment along with the some of the spatial EI maps was used as an input into catchment level analysis for rehabilitation prioritisation for focal EI land cover types using the Analytic Hierarchy Process (AHP), a type of multi-criteria decision model that has been used in South Africa and elsewhere. The 12 input datasets used in the study were under three main criteria: ecosystem health status, hydrological functionality and social benefits. The last criteria incorporated stakeholder feedback on priority areas from workshops in a few villages in the White Kei (Cacadu River is part of the White Kei catchment) and Tsitsa catchments, which was collected by the two MSc students funded under the project. The relevant data for the Crocodile River system was obtained from a literature review of previously published reports.

Aim 3 of the project looked at providing an assessment of how the ecological infrastructure facilitates drought mitigation using hydrological modelling as previous research also supports the links between ecological infrastructure and flow regulation. The hydrological modelling was conducted for two catchments only – White Kei and Tsitsa. The Pitman Model (Pitman GWv3 Model) was selected to represent the runoff regime in natural vs modified catchment areas. Scenarios of natural hydrology are compared with 1990 and 2018 land cover.

Results

The report provides the background on the concept and definition of ecological infrastructure and the definition used in the current report (the one produced by SANBI) as part of Aim 1. The project has adopted the definition and explanation of EI from the South African National Biodiversity Institute's (SANBI) framework: *ecological infrastructure refers to naturally functioning ecosystems that deliver valuable services to people, such as healthy mountain catchments, rivers, wetlands, coastal dunes, and nodes and corridors of natural habitat, which together form a network of interconnected structural elements in the landscape. Ecological infrastructure is therefore the asset, or stock, from which a range of valuable services flow. … Ecological infrastructure is the nature-based equivalent of built or hard infrastructure and is as important for providing services and underpinning socio-economic development.* The research conducted is in the context of the Strategic Water Source Areas which are the source of 50% of the water (mean annual runoff; MAR) in South Africa, Lesotho and Swaziland but they cover only 8% of the land area. The reports refers to literature that supports the proposition of ecological infrastructure providing water security and drought mitigation in the context of climate change projections for South Africa. Notably, the SANBI Framework provides the foundation for linking the investment in EI to the National Development Plan 2030, specifically action 7 (public infrastructure investment focused on transport, energy and water that takes account of disaster risk reduction and protection of freshwater ecosystems) and action 8 (interventions such as restoration and maintenance for ensuring environmental sustainability and resilience to future shocks). The case for value of EI is supported by referring to research done in South Africa, both hydrological, restoration and monetary evaluation. One of the outcomes of the project is a Fact Sheet on the value of maintaining and restoring EI that can be used to support knowledge sharing of the importance of these infrastructures.

To achieve Aim 2, the report presents various spatial datasets related to ecological infrastructure in the three focal catchments, including the National Biodiversity Assessment 2018, and Land cover change. The Sustainable Development Goal (SDG) 15.3.1 indicator was used to identify the location of land degradation in the three catchments using the Trends.Earth plugin in QGIS. SDG 15.3.1 degradation indicator aims "*to monitor the proportion* *of land that is degraded over the total land area*". This indicator aligns with our project's focus of identifying land degradation.The SDG 15.3.1 degradation indicator defines three key sub-indicators:

- **land productivity**: refers to the biological capacity of the land to produce, and it represents the source of all food, fibre and fuel that sustains humans
- **land cover**: is the visible physical and biological terrestrial cover of the Earth, and changes in land cover can identify land degradation
- **soil organic carbon**: contributes towards increasing resilience of land and populations dependent on the land

These sub-indicators are proxies for monitoring key factors and driving variables for assessing the delivery of ecosystem services, and this makes the indicator SDG15.3.1 more comprehensive in its evaluation of land degradation. The results found that a large proportion of the pixels are in stable state in Cacadu catchment and <17% has degraded over the assessment period of 2000 to 2015. In comparison, approximately 41% of the land is degraded in Tsitsa catchment, particularly the lower parts, and 34% in the Upper Crocodile catchment. This degradation information along with other spatial datasets (associated with ecosystem health and hydrological function criteria) and feedback from stakeholders (social benefit criteria) was used as input towards prioritisation for rehabilitation of the four key EI land cover types (wetlands, riparian margins, abandoned croplands and grasslands) using the AHP method. The justification for selecting these four Key EI is presented in Chapter 2. The AHP results are presented as two sets of scenarios: one without inclusion of social benefit and therefore aimed at a catchment scale prioritisation, and secondly with social benefit which is aimed towards areas located close to villages. The results vary across and by catchment and also by the key EI land cover type. The reader is referred to Chapter 3 for the specific results.

Under Aim 3, four anthropogenic-induced land modifications, defined as afforestation, cropland expansion, expansion of settlements, and eroded surfaces, were detected in the catchments. The Pitman hydrological model was applied in two focal catchments – White Kei and Tsitsa, and the simulated impacts of land use under 1990 and 2018 land covers were evaluated. The results clearly demonstrated that land modification in these environments reduces the catchment's capacity to delay rainfall from quickly reaching streams during the wet season. While the observed data (streamflow) in the White Kei were of poor quality and hence verification of the model outputs was difficult, two stream flow gauges in the Tsitsa catchment (T3H009 and T3H006) produced data of sufficient quality to ensure the hydrological model was representing stream flows sufficiently (T35C – T3H009: Nash-Sutcliffe Coef. Eff.

Nat 0.73 and Log 0.705; T35K – T3H006: Nash-Sutcliffe Coef. Eff. Nat 0.704 and Log 0.655). In light of the data availability issues and the difficulties of verifying the modelling outputs in many of the catchments, it should be noted that it was endeavoured to set up the model to reflect processes and catchment characteristics as sensibly as possible (see the theses by Mr Xoxo and Ms Mahlaba for full details).

Discussion

The three aims of the project bring together the evidence in terms of previous research (primarily from South Africa) in addition to analyses conducted under the project to build a case for managing and restoring ecological infrastructure in general in South Africa, and specifically in the three focal catchments. Since water is vital for all life as we know it, for growing crops and for productive rangelands, it is not surprising that hydrological services are the most economically and socially valuable services obtained from healthy catchments. The focal EI under this project are aimed at specifically promoting strong flow regulation ecosystem service. Water flow regulation consists of processes by which rainwater is captured by the soils and underlying geological materials, stored as moisture or groundwater, and released slowly into springs and streams. The structure and state of the vegetation plays a critical role in flow regulation because interactions between vegetation, animals and soils play a critical role in determining soil porosity and, thus, its ability to absorb rainwater and minimise surface runoff during rainfall events. Thus, identifying the location of degradation and prioritising these for rehabilitation is strategic for building strong flow regulation and drought mitigation.

The current project has highlighted mismanaged land uses and certain land cover changes (such as abandoned cultivation areas, overgrazed areas, and presence of invasive alien plants) that are considered to be 'degradation' from the perspective of ecological infrastructure and flow regulation ecosystem service. The degradation indicator based on three land degradation indicators (i.e. land productivity, soil organic carbon and land cover change) in the semi-arid grassland region of South Africa found moderate land degradation in the study catchments. Some of the focal catchment areas are significantly affected by human actions, and the degraded areas are not catchment-wide. The degradation process in the catchments is predominantly localised, highlighting the relevance of the local scale for land management policy planning. Land cover and soil organic carbon stocks largely remained unchanged, while land productivity showed a declining trend, possibly due to natural and human-induced stress. Consequently, land productivity changes influenced the degradation results obtained, suggesting a new degradation process through a moderate reduction in biomass productivity. Therefore, the findings from this study emphasise the need to adopt management interventions in rural grassland ecosystems to protect the security of vulnerable rural communities. Based on the prioritisation findings and the land degradation neutrality framework, the high priority areas are recommended for EI investment to improve water flow regulation, and they would yield other ecosystem benefits for locals.

The modelling exercise which simulated surface runoff dynamics and their changes due to land modification support earlier findings in the Olifants catchment (Gyamfi, Ndambuki and Salim, 2016), where a significant reduction in rangelands and increase in croplands led to nearly 50% more surface runoff. Findings by Gyamfi et al. (2016) are consistent with other literature in South Africa (Rebelo et al., 2015; Mander et al., 2017; Hughes et al., 2018b). Despite the differences in methodology and study contexts, the studies collectively agree that land cover alterations such as those in the White Kei and the Tsitsa catchments combined with climate change impacts intensify surface runoff and result in less resilient catchments regarding drought.

Short Summary Results (Key Findings)

There are a number of key findings supported by this project. Firstly, we have brought together literature which shows that investing in ecological infrastructure is beneficial from point of view of flow regulation and financially. Secondly, we have built a case for supporting the argument that investment in ecological infrastructure enhances catchment water security through promotion of strong flow regulation. We propose that the methodology adopted by our project (as in some others) of integrating stakeholder feedback with spatial information allows for a more meaningful and transformative research that can be implemented because of the buy-in of the stakeholders that is a result of the process of allowing and recognising the choices made by the local community.

These results are aimed both at decision-makers in the government at national and provincial level (particularly, the Department of Agriculture, Forestry and Fishery and the Department of Water and Sanitation) who are responsible for the policy and financial allocations to implement the policy in the catchments. The results are also aimed at NGOs, citizen scientists and other scientists who provide the oversight and feedback on protection and restoration programs on the ground.

In terms of strategic response, public-private partnerships are showing the way of successfully implementing sustainable management programs. A good example is the LandCare programme that was initiated by the former Department of Agriculture (now DEFF) with the aim to mainstream biodiversity in agriculture, forestry and fisheries policies in cooperation with NGOs, private sectors and provincial government practices. This form of public-private partnerships has also been used by DEA-NRM (e.g. uMzimvubu Catchment Partnership Program (UCP), Umngeni Ecological Infrastructure Partnership, Tsitsa Project, WRC Green

Village), and is being promoted through partnerships between the private sector and NGOs (e.g. WWF, Meat Naturally, AWARD). Participatory partnerships such as these offer the affected people agency and capacity are essential bottom up initiatives that coupled with top-down support can be successful way forward that support sustainable land management and the building of sustainable livelihoods.

Conclusions and recommendations for further research

We hope the Fact Sheet generated by the project will be useful for society and government at various levels. It has been written to address the need for presenting the importance of ecological infrastructure in terms of water security. The value of maintaining and restoring EI can be used to support knowledge sharing and providing evidence to decision makers of the importance of these infrastructures. The strategic response for improving water security using ecological infrastructure links with proposed strategies under SANBI's Framework for Investing in EI that can be implemented through public-private participatory partnerships (such as LandCare) that have been found to be successful in getting buy-in and supporting sustainable land management while at the same time building sustainable livelihoods. The report identifies various key areas of knowledge gaps for future research under three categories: on mapping and monitoring the consequences of degradation, on the benefits and monitoring of rehabilitation, and on effective and integrated implementation.

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List of Abbreviations

CBD	Convention of Biological Diversity
CER	Centre for Environmental Rights
CHIRPS	Climate Hazards group Infrared Precipitation with Stations
CR	Critically Endangered
DEA	Department of Environmental Affairs
DEFF	Department of Forestry, Fisheries and the Environment
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EbA	Ecosystem-based adaptation
EI	Ecological Infrastructure
EN	Endangered
EPL	Ecosystem Protection Level
ESA CCI	European Space Agency: Climate Change Initiative
ETS	Ecosystem Threat Status
FEPA	Freshwater Ecosystem Priority Areas
GEF	Global Environment Facility
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LC	Least Concern
LDN	Land Degradation Neutrality
MA	Millennium Ecosystem Assessment
MAE	Mean Annual Evaporation
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MODIS	Moderate Resolution Imaging Spectroradiometer

NBA	National Biodiversity Assessment
NBSAP	National Biodiversity Strategy and Action Plan
NCCRWP	National Climate Change Response White Paper
NDP	National Development Plan
NDVI	Normalized difference vegetation index
NIAPS	National Invasive Alien Plant Survey
NLC	National Land Cover
NLEIP	Ntabelanga Lalini Ecological Infrastructure Project
NPP	Net Primary Productivity
NRM	Natural Resource Management
NWA	National Water Act
NWRS	National Water Resource Strategy
RDM	Resource Directed Measures
RLE	Red List of Ecosystems
RUE	Rain Use Efficiency
SANBI	South African National Biodiversity Institute
SANLC	South African National Land Cover
SDG	Sustainable Development Goal
SOC	Soil Organic Carbon
SRCCL	IPCC Special Report on Climate Change and Land
SRTM	Shuttle Radar Topography Mission
SWSA	Strategic Water Source Areas
SWSA-gw	Strategic Water Source Areas for groundwater
SWSA-sw	Strategic Water Source Areas for surface water
UEI	Urban Ecological Infrastructure
UN	United Nations
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization

VU	Vulnerable
WfW	Working for Water
WWF	World Wide Fund for Nature

CHAPTER 1 PROJECT BACKGROUND

1.1 Motivation, aims and context of the project

> While it is sometimes easy to assume that water security is assured primarily via dams, reservoirs, treatment works and distribution networks, it is in the end nature that replenishes the freshwater that underpins all economic activity.
>
> WWF (2018: p. 15)

South Africa is an arid country with a mean annual rainfall of less than 500 mm, only 9% of which ends up as water in rivers and aquifers (Department of Water Affairs, 2013b), so every drop is scarce and it is imperative that water is used optimally. Water supplies are unevenly distributed, only 8% of the land area yields about half the runoff, and these major water sources need to be managed to protect the quality and quantity of the water they provide. Since most of the high yielding areas are still under natural vegetation, it is critical to ensure that these are maintained for optimal water production.

South Africa has been experiencing a severe drought since 2015, and this has resulted in crop losses, imposition of water restrictions, and significant impacts on water and food security (Department of Environmental Affairs, 2017b). Droughts are likely to become more intense and more frequent in the future due to changing climatic regimes (Department of Environmental Affairs, 2017b); at the same time, energy, land and water demands are expected to increase globally (WWF, 2018). This has implications for the associated impacts on the availability of grasses for livestock, and water and food security (due to crop losses and water availability). It is clear that South African society needs to respond more appropriately to droughts through timeous and transformative interventions, moving away from responses that do not yield long-term gains, to optimise the supply of water resources (Enfors and Gordon, 2008). Across the world, nature-based solutions are being proposed to enhance availability of water, improve water quality and reducing risks of water-related disasters as noted in the World Water Development Report 2018 (WWAP/UN-Water, 2018).

In the past, the normal go-to response for water security in many countries, including South Africa, has been to build dams and institute inter-basin transfers. This approach is still valid, but it should be complemented with the (long-term) approach of protection and rehabilitation of the EI that not only serves the purpose of water security, but it provides additional gains in terms of ecosystem functioning (Hughes et al., 2018b; South African National Biodiversity Institute, 2019). Intact or well-managed EI provide various ecosystem services and services of purifying and supplying fresh water, and thus, they justify protection and management (Postel and Thompson, 2005; Nel et al., 2014). The most economically and socially valuable services that we obtain from healthy catchments are those related to hydrological services, which include water filtration/purification, seasonal flow regulation, erosion and sediment control, and habitat preservation (Postel and Thompson, 2005: Table 1). The approaches for investing in EI are also in line with the National Water Resource Strategy (NWRS2) which promotes rehabilitating strategic water ecosystems and protecting and maintaining freshwater ecosystem priority areas (Department of Water Affairs, 2013b; Skowno et al., 2019a).

Human modifications of catchments (particularly the vegetation for livestock grazing, cultivation, plantations, and settlements) are necessary to meet human needs, but typically they alter how the rainwater is partitioned, often reducing river flows or increasing the volume of floods, or both (Rebelo et al., 2015; Le Maitre, Kotzee and O'Farrell, 2014; IPBES, 2018a). Changes in water flows are also closely linked to sediment flows, and the reduced vegetation cover in heavily- or over-grazed lands or poorly designed cultivation may result in increases in soil erosion. Typically, this triggers a negative spiral with further, more rapid erosion, sedimentation of dams and less usable water. Thus, it is crucial for people to recognise the early stages of such degradation and alter their land-use practices to halt further damage and restore the ecosystems that protect their catchments.

Therefore the aims of the Water Research Commission (WRC) project were:

1. To explain how well-managed ecological infrastructure can help to mitigate the impacts of droughts on human livelihoods and well-being and to propose strategic responses that will maintain and enhance the value of this service that people will embrace and implement.
2. Assessment of ecological infrastructure extent, current state and prioritisation in three focal catchments.
3. To provide an assessment of how the ecological infrastructure facilitates drought mitigation.

Turner et al. (2015) in their review of assessing changes in the value of ecosystem services due to land degradation provide a valuable framework of four direct drivers of land degradation: infrastructure extension (including human settlements, transport, irrigation), agricultural activities (livestock and crop production), wood extraction and related activities (fuelwood harvest, plant and medicinal herb collection) and increased aridity (due to indirect climate variability such as in precipitation, as well as direct impact on land cover through prolonged drought or fire). These drivers are underlain by six social or biophysical causes, namely demographic, economic, technological, political and institutional, cultural, and climatic factors that interact over space and time, making the issue of land degradation complex from a management point of view.

Restoration is being promoted across the world and 2021-2030 has been declared as the UN Decade on Ecosystem Restoration. The idea behind this decade began with The Bonn Challenge which is a global effort for restoring deforested and degraded lands with targets for 2020 (150 million hectares) and 2030 (350 million hectares) beginning in 2011 (United Nations, 2019). The Bonn Challenge was initiated by the German government and the IUCN and on 1 March 2019, the UN Decade on Ecosystem Restoration was declared in order to accelerate the restoration of degraded landscapes. Through this UN declaration, various agencies including the UN Environment Programme (UNEP), UN Food and Agriculture Organization (FAO), International Union of Conservation of Nation (IUCN) and the UN Economic Commission for Europe (UNECE) are targeting restoration of forests, croplands, wetlands, oceans and other natural ecosystems (United Nations, 2019). The reasoning behind this is that land degradation leads to loss of biodiversity and ecosystem services that are worth >10% of annual global gross domestic product according to the UN report. Therefore, ecosystem restoration complements conservation of biodiversity and it can halt degradation of natural ecosystems, help maintain and restore ecological integrity, and provision ecosystem services. However, one must be cautious to consider afforestation in areas that have naturally evolved as savannas and grasslands as planting trees in these areas as a drought mitigation measure could have significant hydrological implications.

Meeting the targets of South Africa's second National Biodiversity Strategy and Action Plan (NBSAP) covering the period 2015-2025 (Government of South Africa, 2015) is through strategies such as the National Biodiversity Framework (NBF) that identify priority actions for management of these resources. The Strategic Objectives of NBSAP 2015-2025 align with various Aichi and SDG goals including SDG goal 15 (Government of South Africa, 2015: p. 64). SDG goal 15 aims to protect terrestrial ecosystems and biodiversity: "*Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss*". A key target for SDG 15 that links to the current project is target 15.3, which aims to "*combat desertification, restore degraded land and soil, and to foster ways to achieve a land degradation-neutral world*" (United Nations, 2015).

Goal 15 (Life on land): Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

Two other relevant Sustainable Development Goals (SDGs) related to the overall context of this project are:

Goal 6 (Clean water and sanitation): Ensure availability and sustainable management of water and sanitation for all.

Goal 13 (Climate change): Take urgent action to combat climate change and its impacts.

1.1.1 Previous mapping of land degradation in South Africa

> We are all asset managers. Whether as farmers or fishers, foresters or miners, households or businesses, governments or communities, we manage the assets to which we have access, in line with our motivations as best as we can…. In the process of getting to where we are, though, we have degraded the biosphere to the point where the demands we make of its goods and services far exceed its ability to meet them on a sustainable basis. That suggests we have been living at both the best and worst of times.
>
> Dasgupta (2021: p. 11)

Various attempts have been made in the past to identify the degradation areas for South Africa. Identifying the location and the reasons behind land degradation in the landscape is first step for designing a response strategy. In 2000, Hoffman and Todd published a national review of land (soil and veld) degradation based on participatory workshops with employees of the Department of Agriculture. They noted that veld degradation was high in communal areas (compared to commercial areas) due to issues of bush encroachment and invasion by alien plants. Secondly, they noted a link between degradation and biophysical (slope steepness and mean annual temperatures) and socio-economic factors (rural communities where significant amount of the population is dependent on a few wage earners). The map of combined soil and veld degradation published by Hoffman and Todd (2000) shows the spatial pattern with the former Ciskei, Transkei and KwaZulu communal areas being the most degraded (Figure 1-1).

More recently, data for degraded areas has been available at a higher resolution as part of South Africa's 2009 National Land Cover (NLC) dataset generated by SANBI (Figure 1-2). The Figure shows the overlap of degradation areas in the 2009 NLC with the South African Strategic Water Source Area (SWSA) including both surface water and ground water areas, which highlights the importance of managing and prioritising these areas. In general, the maps created by Hoffman and Todd (2000) and the 2009 NLC show similar spatial pattern. Figure 1-2 also shows the overlap of degradation areas in the 2009 NLC with the South African strategic water source areas (SWSA), including both surface water and ground water areas, which highlights the importance of managing and prioritising these areas. The 2009 NLC was generated using a combination of different provincial datasets (from 2000-2008) with the NLC2000.

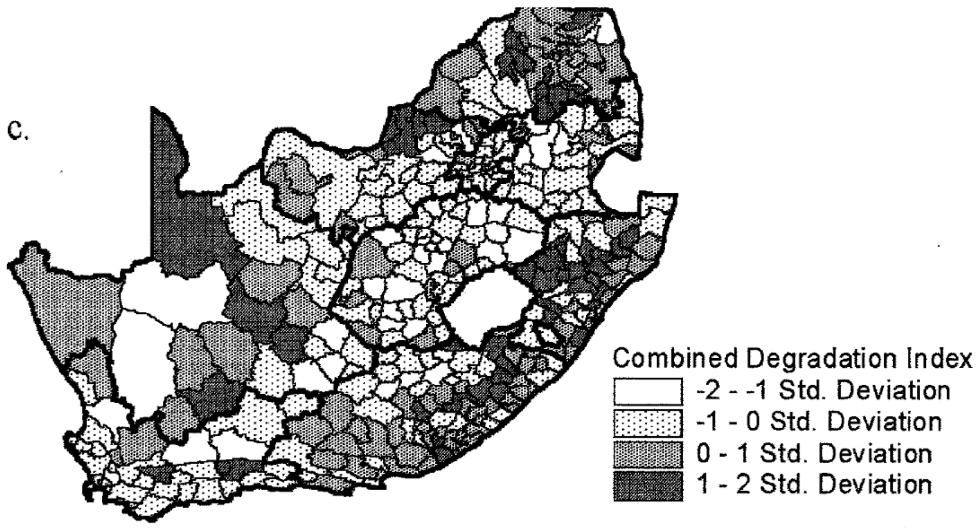


Figure 1-1 Combined index of soil and vegetation degradation at district level generated by Hoffman and Todd (2000: p. 752)

1.1.2 Special Report on Climate Change and Land (SRCCL) and land degradation

> As climate change intensifies, nature's value is only increasing. It will play an essential role in helping human societies cope with the inevitable consequences of rising global temperatures. These include rising sea levels, more extreme rainfall, more frequent droughts and more frequent and intense storms – all impacts that NATO and the Pentagon recognize as significant threats to global security. Healthy natural systems can help reduce the damage caused by these changes
>
> WWF (2018: p. 15)

Climate change and variability is expected to result in greater land degradation and desertification and thereby water and food security, as noted in the title of the recently released 2019 IPCC Special Report on Climate Change and Land (SRCCL): 'Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems'. As a response, sustainable land management is proposed as an adaption and mitigation strategy for climate change (Intergovernmental Panel on Climate Change [IPCC], 2019).

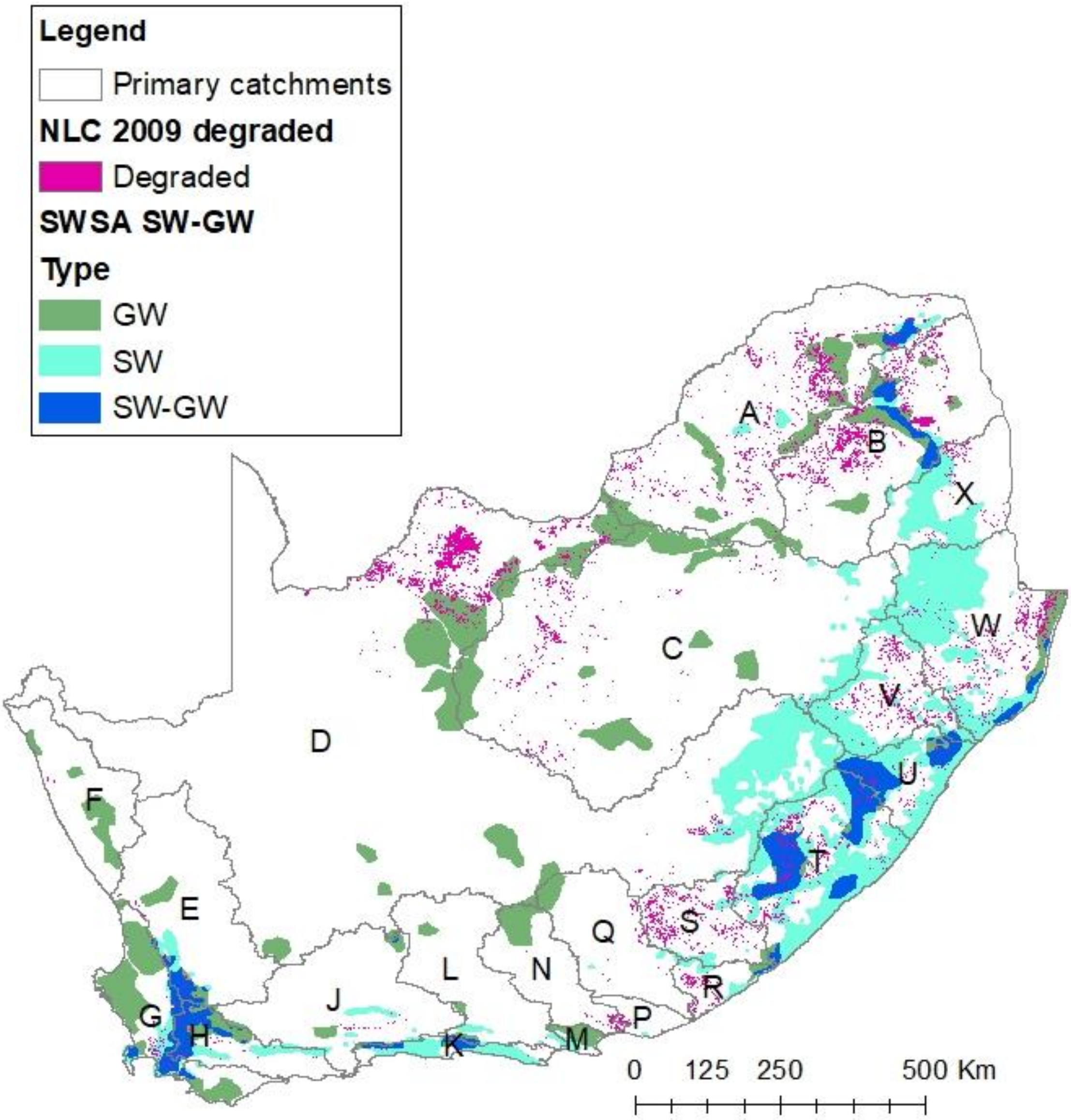


Figure 1-2 Location of degraded natural vegetation in South Africa in NLC 2009 (South African National Biodiversity Institute, 2009) relative to the strategic water source areas, both groundwater and surface water (Nel et al., 2017) by primary catchments

The following two sections provide some of the relevant findings from the SRCCL report that are important to consider as support for the case for ecological infrastructure and water related ecosystem services.

1.1.3 Land management links to desertification in SRCCL

The following are the Medium and High confidence global findings on desertification, the links to climate change and the need for Sustainable Land Management (SLM). SLM is defined as "the stewardship and use of land resources, including soils, water, animals and plants, to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions" (Intergovernmental Panel on Climate Change [IPCC], 2019: p. 1), which is equivalent to the term "well-managed ecological infrastructure" in our report. The following quotes are from Chapter 3 of the SRCCL report (the bold highlighting is from the project team):

A. Desertification is land degradation in arid, semi-arid, and dry sub-humid areas, collectively known as drylands, resulting from many factors, including human activities and climatic variations. **The range and intensity of desertification have increased in some dryland areas over the past several decades** (high confidence).

B. Desertification and climate change, both individually and in combination, will reduce the provision of dryland ecosystem services and lower ecosystem health, including losses in biodiversity (high confidence).

C. Increasing human pressures on land combined with climate change will reduce the resilience of dryland populations and constrain their adaptive capacities (medium confidence).

D. Investments into SLM, land restoration and rehabilitation in dryland areas have positive economic returns (high confidence).

E. Policy frameworks promoting the adoption of SLM solutions contribute to addressing desertification as well as mitigating and adapting to climate change, with co-benefits for poverty reduction and food security among dryland populations (high confidence).

F. Implementation of Land Degradation Neutrality policies allows to avoid, reduce and reverse desertification, thus, contributing to climate change adaptation and mitigation (high confidence).

The concept of land degradation neutrality (LDN) was introduced in 2012 (20 years on from the 1994 United Nations Convention to Combat Desertification (UNCCD)) as a means for countries to keep stable (or increase) the ecosystem functions and services (Chasek et al., 2019). LDN has been incorporated into SDG 15 as target 15.3 (achieving land degradation neutrality by 2030).

The socio-economic impacts of desertification and climate change together on the SDGs highlighted in the SRCCL are highlighted in Figure 1-3 (IPCC, 2019). Of note are the interactions and impacts between climate change (SDG 13) and life on land (SDG 15 including desertification) that are both high level of confidence and high magnitude of impact; this highlights the need for integrating climate action into achieving SDG 15 and land degradation neutrality.

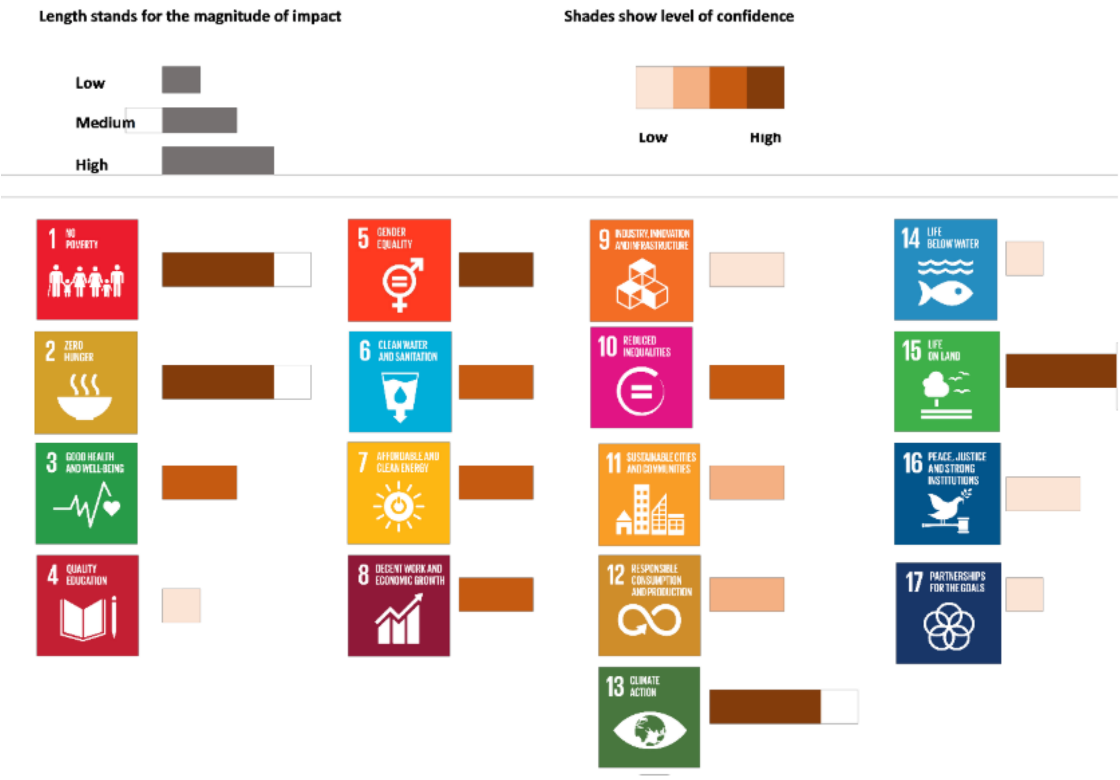


Figure 1-3 Socio-economic impacts of desertification and climate change on SDGs (source: IPCC, 2019: p. 3-35).

1.1.4 Land management as a means to climate change adaptation and mitigation in SRCCL

Chapter 4 of the SRCCL focuses on land degradation, which the report defines as "*a negative trend in land condition, caused by direct or indirect human-induced processes including anthropogenic climate change, expressed as long-term reduction or loss of at least one of the following: biological productivity, ecological integrity or value to humans"* (IPCC, 2019: p. 4-9) and the following are the Medium, High and Very High confidence global findings on land degradation and the links to climate change (note the bold highlighting is from the project team):

- **Land degradation adversely affects people's livelihoods** (very high confidence) and occurs over a quarter of the Earth's ice-free land area (medium confidence).
- Climate change exacerbates the rate and magnitude of several ongoing land degradation processes and introduces new degradation patterns (high confidence).
- Global warming beyond that of present-day will further exacerbate ongoing land degradation processes through increasing floods (medium confidence), drought frequency and severity (medium confidence), intensified cyclones (medium confidence), and sea-level rise (very high confidence), with outcomes being modulated by land management (very high confidence).
- Land degradation and climate change, both individually and in combination, have profound implications for natural resource-based livelihood systems and societal groups (high confidence).
- **Land degradation is a driver of climate change** through emission of greenhouse gases and reduced rates of carbon uptake (very high confidence).
- Land degradation can be avoided, reduced or reversed by implementing sustainable land management, restoration and rehabilitation practices that simultaneously provide many co-benefits, including adaptation to and mitigation of climate change (high confidence).
- **Lack of action to address land degradation will increase emissions and reduce carbon sinks** and is inconsistent with the emission reductions required to limit global warming to 1.5°C or 2°C (high confidence).

The SRCCL report presents a conceptual framework for the potential outcome of sustainable versus degradation due to the interaction between climate change impacts and land management, which is shown in Figure 1-4. The figure highlights how sustainable forest and agriculture practices, which include restoration and rehabilitation, can result in these areas being less degraded and net carbon uptake sinks.

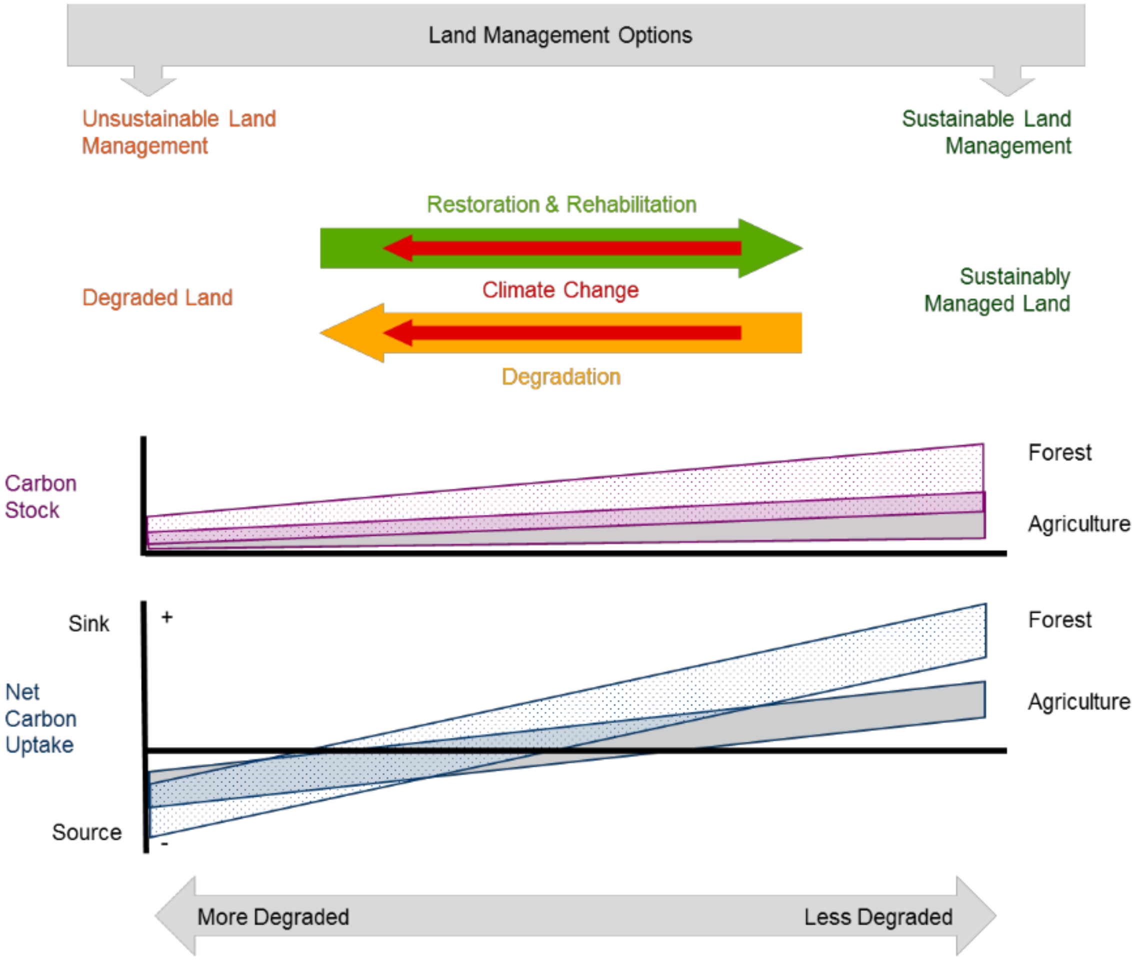


Figure 1-4 SRCCL's conceptual framework for the interaction between climate change impacts and land management, which can result in degraded or sustainably managed land (IPCC, 2019: p. 4-13).

1.2 Concept and definition of ecological infrastructure and ecosystem services

The term 'ecological infrastructure' (EI) was first proposed in 1984 as a guiding principle for sustainable urban planning under the Man and Biosphere (MAB) program (UNESCO, 1984; da Silva and Wheeler, 2017). The EI concept supports the idea of the benefits of ecosystem services to people and the environment (Cumming et al. 2017). Interestingly, Yu, Li, and Li (2008) relate the EI concept as applied to urban planning, to the ancient Chinese art of *Feng-shui*, i.e. 'sacred landscape setting for human settlement'. More recently, Feng Li and others (2017: S12) delineated a specific EI category, named Urban EI (UEI), which they define as "an organic integration of blue (water-based), green (vegetated), and grey (non-living) landscapes, combined with exits (outflows, treatment, or recycling) and arteries (corridors), at an ecosystem scale"

Since the 1980s, various terms, besides ecological infrastructure, have been used to encompass the concept of ecosystems as infrastructure, such as 'green infrastructure'. da Silva & Wheeler (2017: p. 33) define green infrastructure as

> *a network of natural, semi-natural and restored areas designed and managed at different spatial scales (from local to global), that encompasses all major types of ecosystems (marine, terrestrial and freshwater), and that aims to conserve biodiversity, mitigate emissions of greenhouse gases, enable societal adaptation to climate change, and deliver a wide range of other ecosystem services*

Shackleton et al. (2017: p. 232) similarly define the term green infrastructure (or functional ecological infrastructure) as "*naturally functioning ecosystems and cultural landscapes that deliver valuable services to people*". Other researchers (e.g. Matthews, Lo and Byrne, 2015), however, define 'green infrastructure' strictly in terms of biological resources in urban areas that are human-modified and qualify them to have been designed for public use and benefit; these authors promote adoption of these spaces by spatial planners as a climate adaptation measure.

Box 1-1 Definition of EI used in this report

Considering the overlap in terminology that is related to natural capital that provides benefits in terms of goods and services, and since this report is in the context of South Africa, we have adopted the following definition and explanation of EI from the South African National Biodiversity Institute's (SANBI) framework (2014: p. 3):

> *ecological infrastructure refers to naturally functioning ecosystems that deliver valuable services to people, such as healthy mountain catchments, rivers, wetlands, coastal dunes, and nodes and corridors of natural habitat, which together form a network of interconnected structural elements in the landscape. Ecological infrastructure is therefore the asset, or stock, from which a range of valuable services flow. … Ecological infrastructure is the nature-based equivalent of built or hard infrastructure and is as important for providing services and underpinning socio-economic development.*

The definition in Box 1-1 highlights the importance of various land cover categories that are naturally occurring, which when in healthy condition are capable of providing a range of ecosystem services (Shackleton et al., 2017; da Silva and Wheeler, 2017; Le Maitre, Kotzee and O'Farrell, 2014). This project aims to contribute to this knowledge area by looking at the links between ecological infrastructure and water security.

1.2.1 Ecosystem services: water provisioning and flow regulation

South Africa's scarce freshwater resources, together with increasing water quality issues, have raised the profile of water resources and highlighted the many deficiencies in water governance and management. We have known for a while that changes in ecosystems can result in non-linear changes in ecosystems and impact on the ecosystem services that are essential to us (Millennium Ecosystem Assessment (MA), 2005b) (Blignaut and Aronson, 2008). This flow is dependent on renewable natural capital, which comprises functioning ecosystems and native biodiversity. Various studies have investigated the links between land-use or degradation and its hydrological impacts (e.g. USA: Schilling et al., 2008; China: Lin et al., 2015; East Africa: Guzha et al., 2018) and these links have also been examined from an ecosystem services perspective (e.g. *South East Asia*: Tomich, Thomas and Van Noordwijk, 2004; *South Africa*: Rebelo et al., 2019). This chapter aims to explore this relationship between land degradation and flow regulation based on evidence from South African research (supported by international studies where required).

Flow regulation ecosystem service, which is regulation of the hydrological cycle in terms of flood and drought mitigation, is affected by land management practices; thus, the land uses and the associated practices are important for climate resilience. The reliability of the temporal and spatial patterns in the volume of water supplied (**water provisioning**) is part of the flow regulation ecosystem service. Thus, the water supply or water provisioning service is the outcome of the water regulatory service, which if altered significantly, impacts on biodiversity (Onaindia et al., 2013). The presence and type of vegetation impacts on various processes including water-use (transpiration, interception), soil stabilisation, infiltration of rainfall to recharge groundwater supplies that are particularly important source of the baseflow in rivers during the dry season (Dominati et al., 2014; Rebelo et al., 2015; Van der Waal and Rowntree, 2018). Vegetation also influences the rate of water entering the rivers as runoff from land, which affects flood peaks (Le Maitre et al., 2007). The link between sustainably managed land and water related ecosystem services is thus critical for resilient landscapes for people (Figure 1-5). Land use practices and land cover can modify the processes listed above and thus impact the hydrological regime in terms of baseflows and flood peaks (Le Maitre, Kotzee and O'Farrell, 2014). Studies have shown how clearing of natural vegetation, especially forests, is followed by an increase in surface runoff and river discharge (Sahin & Hall, 1996; Costa, Botta, & Cardille, 2003). The division between infiltration (which recharges groundwater) and overland flow determines the amount of water that is transported as surface water contribution to a river. The increased surface runoff changes the flow regimes in rivers and possibly increases the frequency of flash flooding in the catchments (Le Maitre et al., 2007).

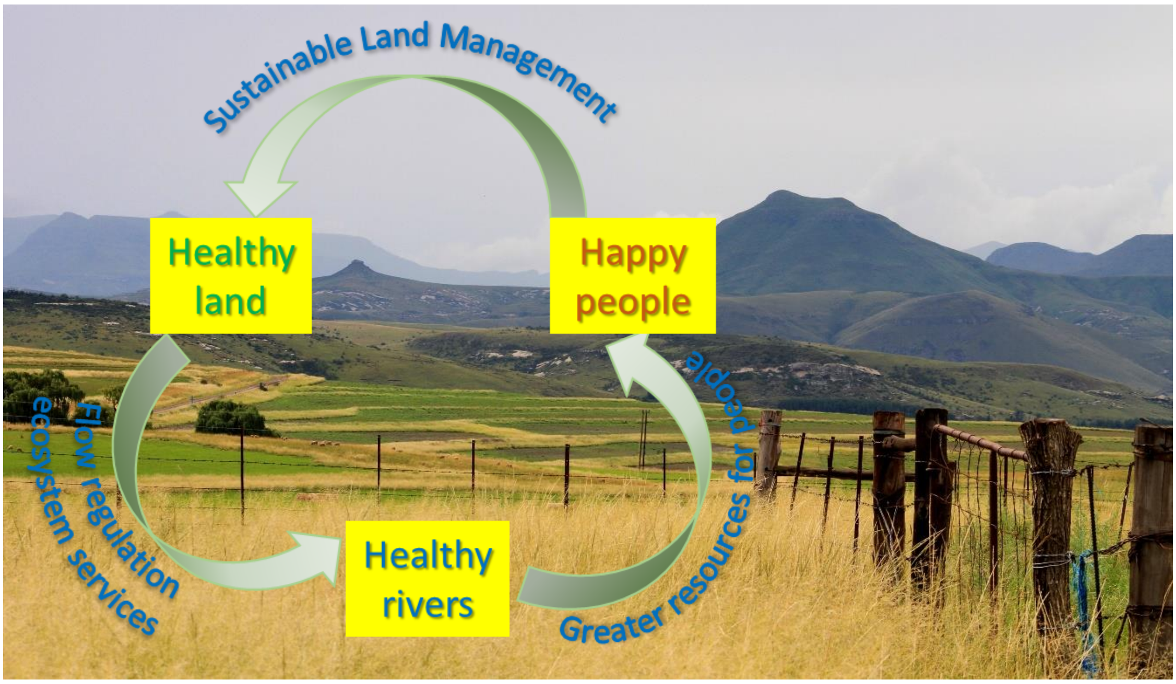


Figure 1-5 Investment in EI is a strategy for accumulating various benefits to people including water and food security, and it requires maintaining functioning EI and restoring degraded EI

1.3 Background and justification of project focal catchments

This project focuses on three catchments, namely the White Kei River (upper catchment of the Groot Kei where Machubeni villages are located; S10 and S20), Tsitsa River (upper uMzimvubu River catchment; T35A-M) and upper Crocodile River (Inkomati; X21). These catchments were selected for three main reasons: current or historical collaborations (necessary for including the communal perspectives and integrating with other research), knowledge of the problems of degradation in the area, and the importance of rural livelihoods in the catchments. Additionally, we considered the location of strategic water source areas in terms of high yield that are located in the eastern and southern part of South Africa.

1.3.1 South Africa's Strategic Water Source Areas and focal catchments

The Strategic Water Source Areas (SWSA) are the source of 50% of the water (mean annual runoff; MAR) in South Africa, Lesotho and Swaziland but they cover only 8% of the land area (Le Maitre et al., 2018a). In 2018, South Africa redefined the Strategic Water Source Areas (SWSAs; Figure 1-6) from the original definition in 2013 (WWF-World Wide Fund for Nature, 2013) that only included surface water SWSAs. The new evaluation includes 22 surface water SWSA-sw (including areas in Lesotho and Swaziland) and 37 groundwater SWSA-gw (only defined for South Africa) (Le Maitre et al., 2018). These areas generate relatively large quantity of mean annual surface water runoff for their size and/or high groundwater recharge. The

SWSA-sw are in areas that receive high rainfall and with baseflow greater than 11-25 mm/a. The SWSA-gw are the source of 42% of the baseflows in their areas but they cover only 9% of the land area (Le Maitre et al., 2018; Figure 1-6). A relative small proportion (11%) of the SWSAs are in protected areas, with the best-protected ones being in the Western Cape. Areas with high mean annual runoff (MAR) SWSA-sw have been prioritised by the Working for Water programme for invasive plants clearing. The location of the focal catchments for this project shown in Figure 1-7 highlights their importance in terms of SWSAs. The case study sections below provide a detailed view of the SWSAs in the study catchments.

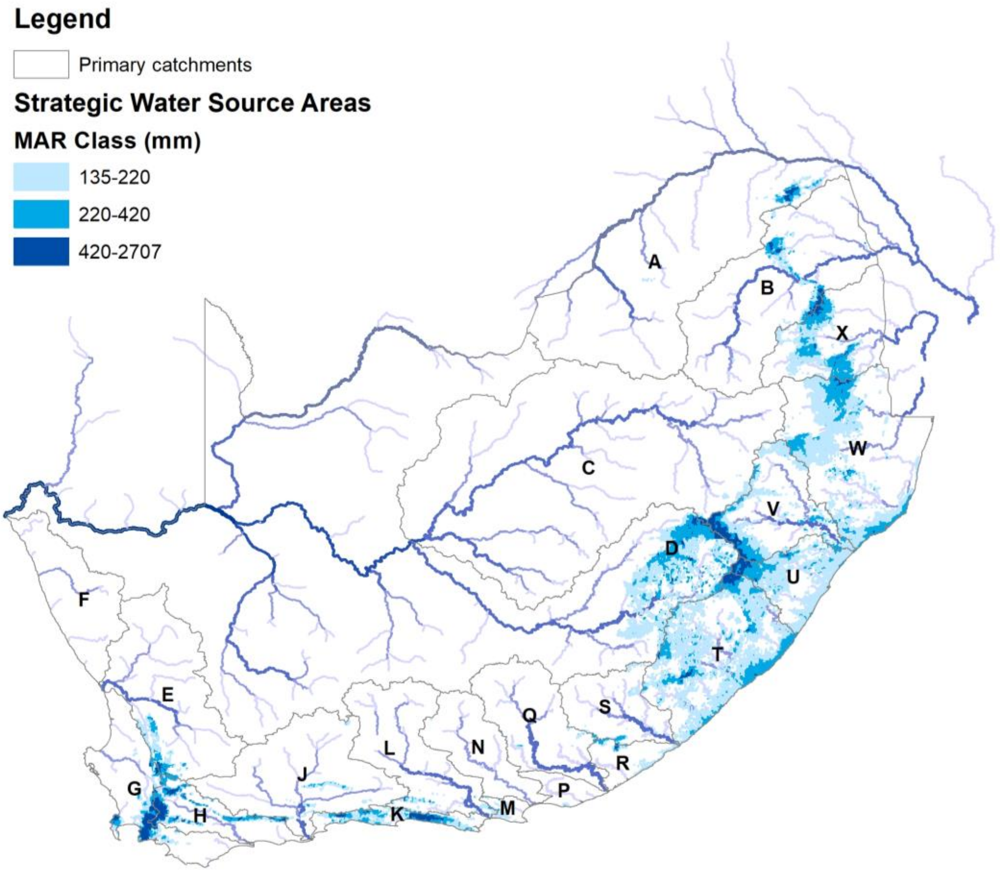


Figure 1-6 Location of Strategic Water Source Areas (SWSA) (Le Maitre et al., 2018a) in relation to the primary catchments and the rivers (order 3-7; Department of Water and Sanitation)

The WWF report further estimated that 63% of these SWSA are in a natural condition with cultivation being the major modifier of natural land cover (15% of SWSA area in South Africa) (WWF-World Wide Fund for Nature, 2013). The other major categories of changed land cover are plantations (13%), urban (4%) and degraded areas (3%) (Table 1-1). Considering that only 16% of the South African SWSA land area is under legal protection of any sort (see Tables 4, 5 and 6 of WWF-World Wide Fund for Nature, 2013 for details), there is need for managing and restoring this area for long-term sustainability of our water resources. The Centre for Environmental Rights calls these areas our "crown jewels" (CER, 2019) and stresses (as does other research and reports) that the health of the natural land cover areas (the ecological infrastructure) is critical as they underpin and support built infrastructure such as dams. These areas are also the foundation of a significant proportion of our social and economic activities: supporting 60% of South Africa's population, 67% of the economic activity and 70% of irrigation water (https://water.cer.org.za/about/the-backdrop; accessed 19 October 2019).

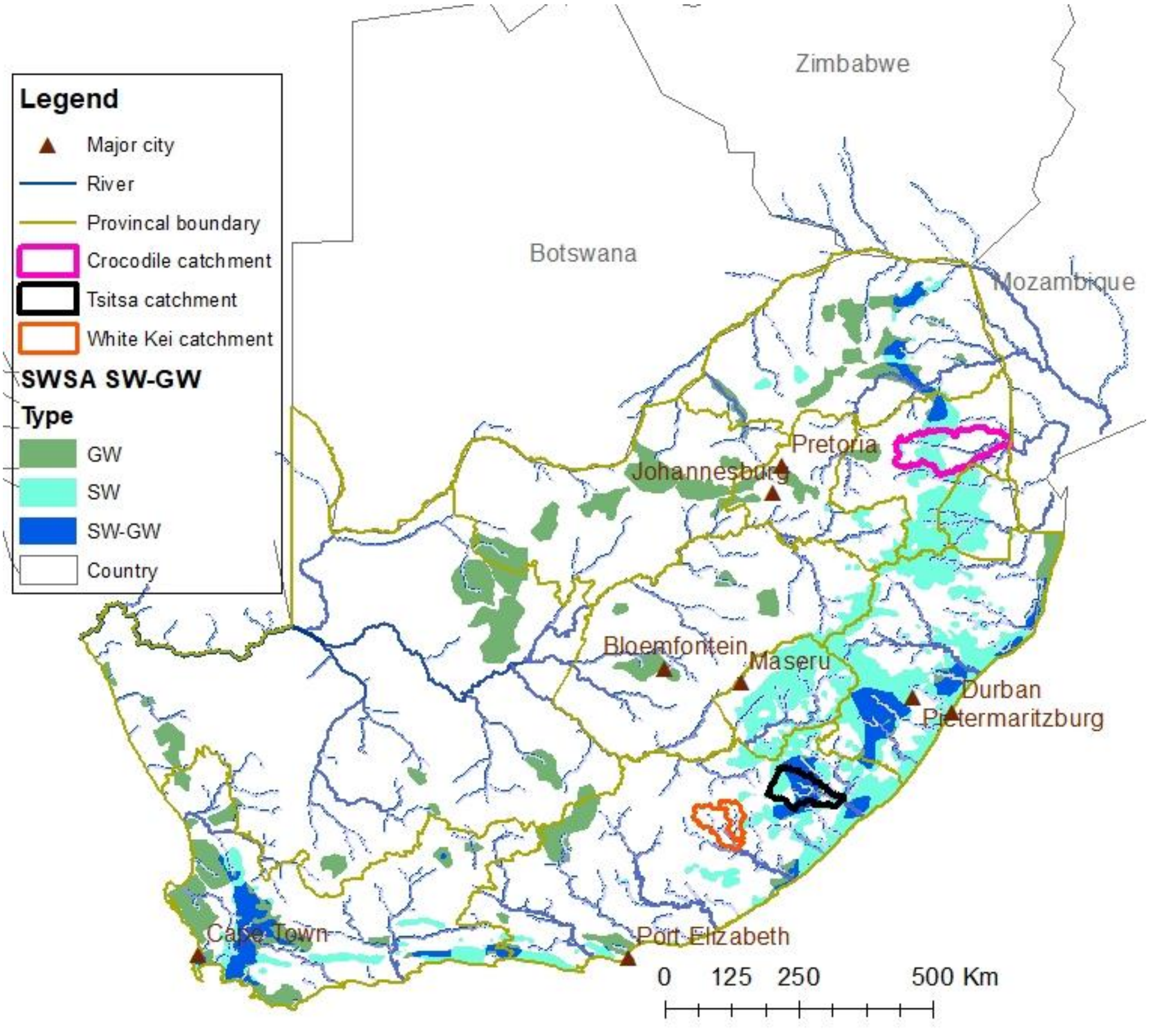


Figure 1-7 Location of project focal catchments relative to the strategic water source areas, both groundwater and surface water (Le Maitre et al., 2018a). All other datasets are from Department of Water and Sanitation

The project's three focal catchments are located in the Eastern Cape and Mpumalanga (see Case Study sections below). The WWF (2013) report notes that cultivation is the major contributor to land cover modification in the Eastern Cape, while almost half of the land cover in Mpumalanga is modified, with plantations comprising a large proportion of that modification. The three selected catchments are good representatives of these generalities, as the following text shows. Table 1-2 is derived from the South African National Land Cover (SANLC) 2017/18 (Department of Environmental Affairs, 2018), and it indicates that grasslands in the Eastern Cape catchments and natural wooded land in the Mpumalanga catchments, are the dominant land covers. The natural wooded land category in SANLC 2017/18 combines three land cover categories from SANLC 2013/14 (Department of Environmental Affairs, 2015a) that are namely, (a) Forest, (b) Thicket & Dense Bush, and (c) Woodland / Open Bush. Cultivated land occupies approximately 15% of the land cover categories in the Eastern Cape catchments and just over 8% in Crocodile catchment, according to SANLC 2017/18 (Table 1-2). Planted forests (plantations) represent over 18% of the modified land cover in Crocodile catchment and these cover 7.5% of the Tsitsa catchment (Table 1-2). The location of these land covers are presented as maps in the following sections.

1.3.2 National level degraded land cover datasets: 2009 NLC and invasive aliens

As mentioned in Section 1.1.1 and Figure 1-2, South Africa's degraded natural vegetation is recorded in the 2009 National Land Cover (NLC) dataset generated by SANBI (South African National Biodiversity Institute, 2009). One limitation of this dataset is that it is based on remote sensing for a portion of the country and it was not standardised for the whole country. As noted in Box 1-2, this dataset only presents degraded natural vegetation, whereas in the context of ecological infrastructure, mismanaged land uses and certain land cover changes are also part of land degradation.

Box 1-2 Degradation in 2009 NLC and in the context of ecological infrastructure

The category 'degraded' in 2009 NLC encompasses four categories in the NLC2000: Degraded Forest & Woodland; Degraded Thicket, Bushland, etc.; Degraded Shrubland and Low Fynbos; and, Degraded Unimproved (natural) Grassland. Thus, the 2009 NLC dataset of degraded areas is strictly in terms of degraded natural vegetation. The current project has not only looked at degraded natural vegetation, but also mismanaged land uses and certain land cover changes (such as abandoned cultivation areas, overgrazed areas, and presence of invasive alien plants) that are considered to be 'degradation' from the perspective of ecological infrastructure and flow regulation.

Table 1-1 Percentage of land cover category in the water sources areas by province and country sourced from (WWF-World Wide Fund for Nature, 2013)

	Natural	Cultivated	Degraded	Urban built-up	Waterbodies	Plantations	Mines
Eastern Cape	67	20	4	3	0	4	0.01
Free State	95	2	1	1	1	1	0
KwaZulu-Natal	60	18	2	6	2	12	0.06
Limpopo	51	14	4	7	1	23	0
Mpumalanga	51	3	2	1	5	37	0.02
Western Cape	76	12	2	3	2	6	0
South Africa	63	15	3	4	2	13	0.03
Lesotho	75	10	13	0	1	0	0
Swaziland	65	11	9	3	0	12	0

Table 1-2 Land cover summary for focal catchments derived from SANLC 2017-18 (Department of Environmental Affairs, 2018)

Land Cover 2017/18	White River (S10-20)	Tsitsa River (T35)	Crocodile River (X21)
Barren land	0.3%	0.5%	0.4%
Build-up	6.7%	6.8%	3.8%
Cultivated	15.5%	14.7%	8.2%
Grassland	67.3%	61.2%	19.4%
Mines and quarries	0.0%	0.0%	0.1%
Natural wooded land	7.9%	5.1%	47.8%
Planted Forest	0.1%	7.5%	18.1%
Shrubland	1.2%	1.5%	0.2%
Waterbodies	0.6%	0.3%	0.3%
Wetlands	0.3%	2.4%	1.8%

Invasive alien plants and bush encroachment have been identified as high priority concerns in South Africa due to their impacts on land degradation, water security and biodiversity (Wilgen et al., 2012; O'Connor, Puttick and Hoffman, 2014; von Maltitz et al., 2019; Skowno et al., 2019a). Due to the lack of extensive natural forests, plantations of introduced, or alien, tree species were established in higher rainfall areas to provide timber, fibre and fuelwood. Unfortunately, many of these tree species are aggressive invaders and have spread beyond plantation areas. There are various other reasons for the widespread presence of wattle in South Africa, including the abandonment of extensive areas of wattle on commercial farms when the tan bark market collapsed in the 1960s, and the establishment of extensive woodlots of black and silver wattle in the former homelands from the late 1800s onwards to try to reduce wood use from indigenous forests. Other plants have been introduced accidently and currently 327 plant taxa are included in the national legislation (Richardson et al., 2020) and these are the motivation for the Working for Water (WfW) programme under Department of Forestry, Fisheries and the Environment (DEFF) (Wilgen et al., 2012). These invasions have the same levels and kinds of impacts as plantations, and even greater impact where the trees invade riparian zones and can access more water (Le Maitre, Gush and Dzikiti, 2015). Invasive aliens impact on water flow regulation through increase in evaporation (through greater interception and transpiration) thus leading to less water entering streams, and this eventually effects the yield from the reservoirs (Le Maitre, O'Farrell and Reyers, 2007; Le Maitre et al., 2019, 2020: Table 15.2). The map in Figure 1-8 (sourced from Le Maitre et al., 2016) shows that the estimated percent reduction in natural MAR by quaternaries due to invasive alien plants and the map indicates that the coastal catchments in north, east and south of South Africa are significantly impacted. The estimate of total loss of surface water runoff by invasive plants is 1.44 to 2.44 billion m^3 for the country and this is projected to increase by 50% if no action is taken (Le Maitre et al., 2020). The location of the invasive aliens also changes the magnitude of the impact and it is estimated that in riparian zones the impact could be 1.2 to 2 times higher (Le Maitre et al., 2020). Thus, evaluating the hydrological impacts and rehabilitation of ecological infrastructure is receiving attention from researchers, although implementation on the ground is lagging (e.g. Mander et al., 2017; Hughes et al., 2018).

The most comprehensive invasive alien plants dataset (with 28 taxa) was generated by Kotzé et al. (2010) and this dataset was one of the inputs for the calculations by Le Maitre et al. (2016) that are presented in the map in Figure 1-8. The location of the three focal catchments relative to the average density of invasive plants derived from this dataset are presented in Figure 1-9. The case study sub-sections below present more detailed maps of invasive alien plants derived from this dataset for the three focal catchments.

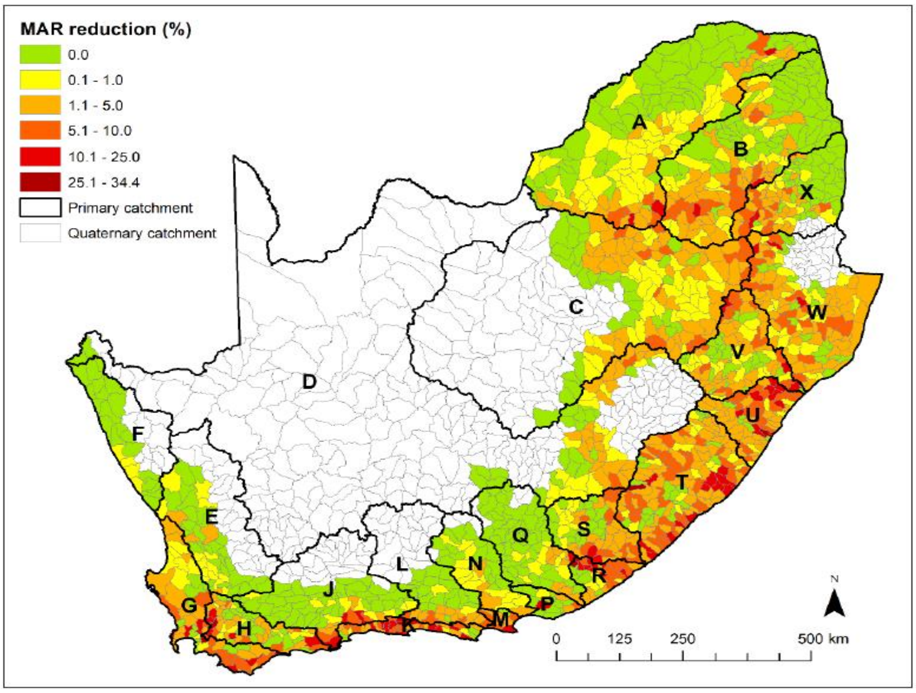


Figure 1-8 Percentage naturalised MAR reduction by quaternary catchments due to invasive aliens generated by Le Maitre et al. (2016: Figure 5)

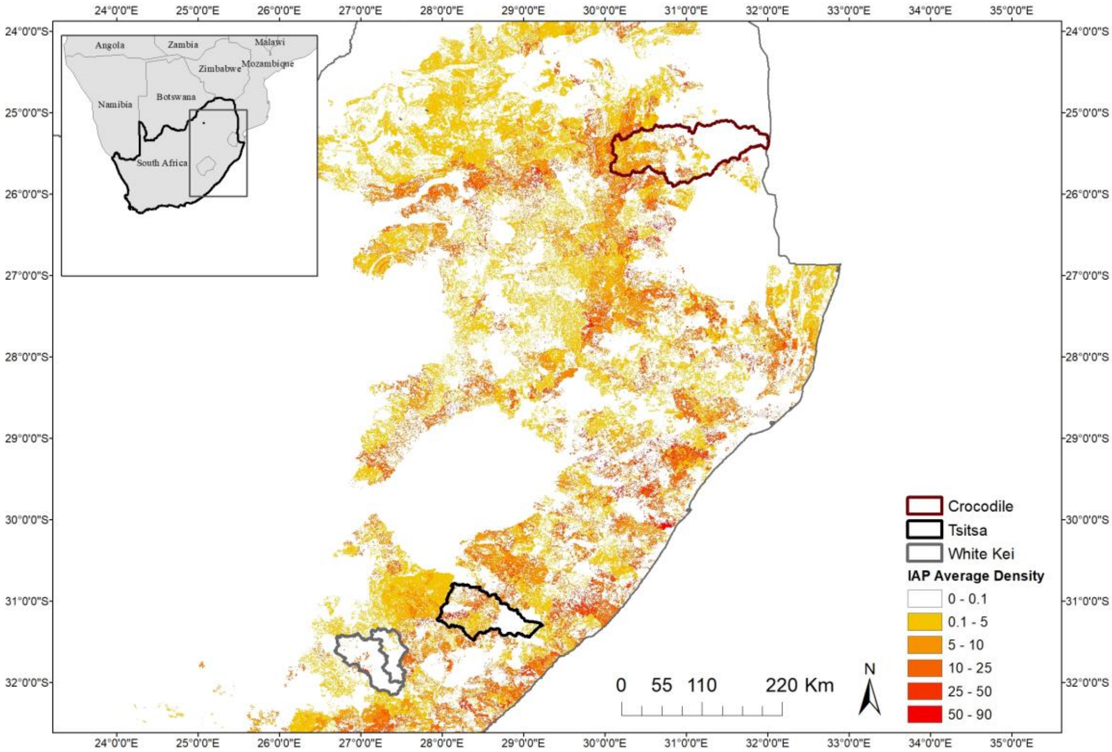


Figure 1-9 Project focal catchments shown with the backdrop of average density of invasive alien plants per homogeneous mapping unit derived from the National Invasive Alien Plant Survey (NIAPS; Kotzé et al., 2010)

1.3.3 Case study 1: White Kei River catchment (hosting Machubeni villages)

The Machubeni villages form one of three focal areas for the GEF5 (Global Environment Facility) project under Dr James Gambiza of Rhodes University. This area is located in the upper mountainous catchment area of White Kei (S10-S20) (Figure 1-10), which is a tributary of the Groot Kei in the Eastern Cape. Our collaboration with this GEF5 project services their project's work on rural communities, particularly those in traditional land-tenure systems that rely on agriculture for their livelihoods. According to the 2011 Census data, the total population of Machubeni in 2011 was 5,817 people, living in 1,595 households from 14 villages (Statistics South Africa, 2011). Livelihoods in the area include subsistence crop farming, livestock farming, and extraction of natural resources (e.g. brick making soil, coal, fuelwood, fruits, medicinal plants). Some of the common crops that are grown include maize, beans, pumpkin and oats for animal feed, while livestock includes cattle, sheep, goats, poultry and donkeys.

The catchment experiences a mean annual precipitation (MAP) between 400 and 950 mm according to WR2012 (Bailey and Pitman, 2015), with Machubeni area receiving rainfall in the lower end of this range (Figure 1-11). Potential evaporation ranges between 1560 and 1950 mm per year (Figure 1-12) and mean annual runoff ranges between 22-124 mm for the S10-S20 tertiaries (Figure 1-13). SANLC 2017-18 for the White Kei catchment shows that the cultivated and built-up areas are spread across the catchment (including in Machubeni area) and these are interspersed in the grassland areas (Figure 1-14).

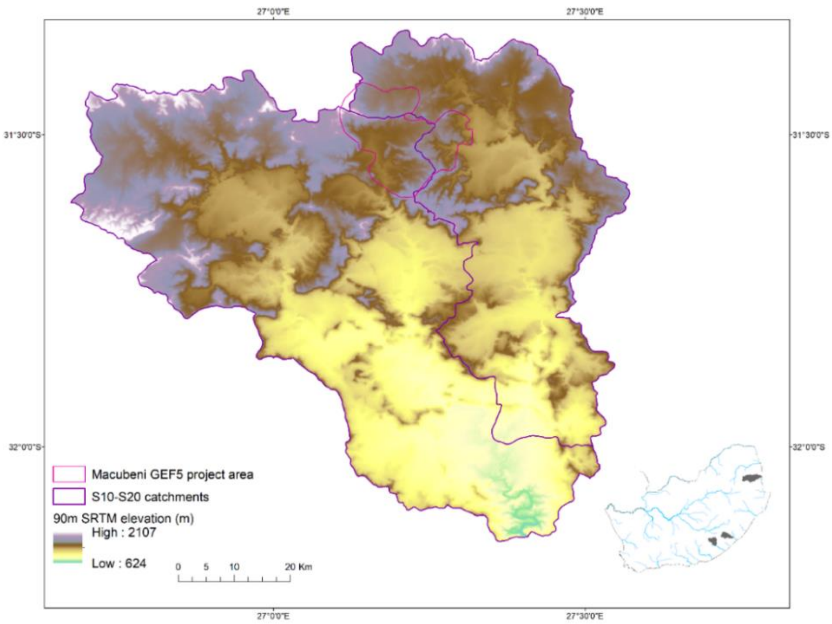


Figure 1-10 Elevation profile (90 m SRTM digital elevation model; Jarvis et al., 2008) for the White Kei catchment in the upper reaches of Groot Kei, with GEF5 Machubeni area in the upper catchment

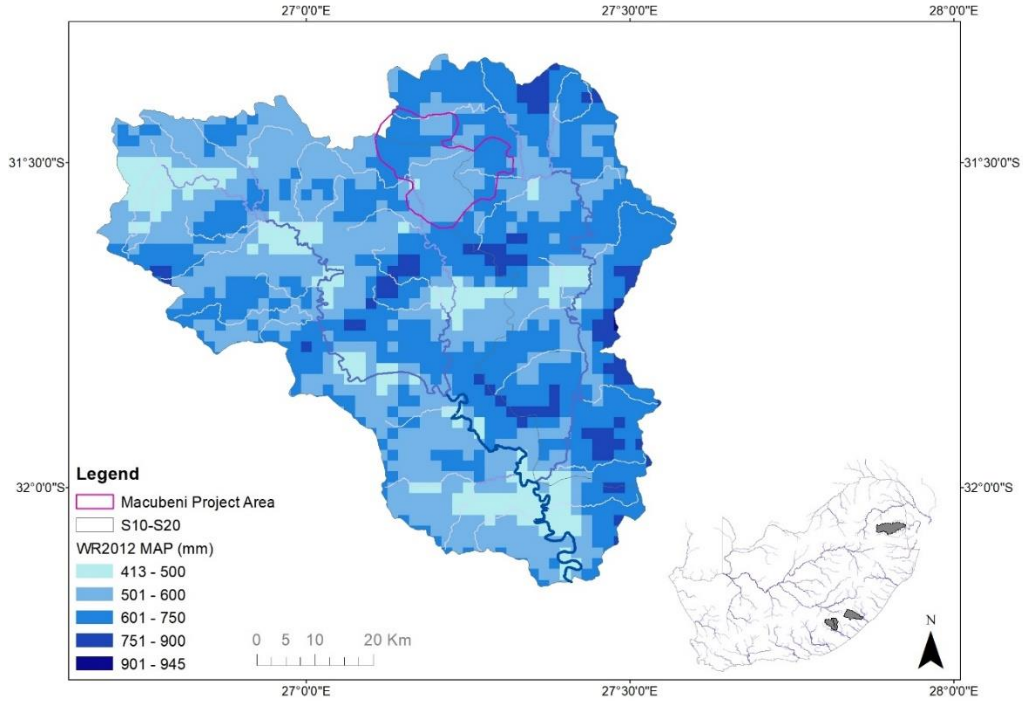


Figure 1-11 Mean annual precipitation (MAP, in mm) derived from WR2012 (Bailey and Pitman, 2015) for the White Kei catchment

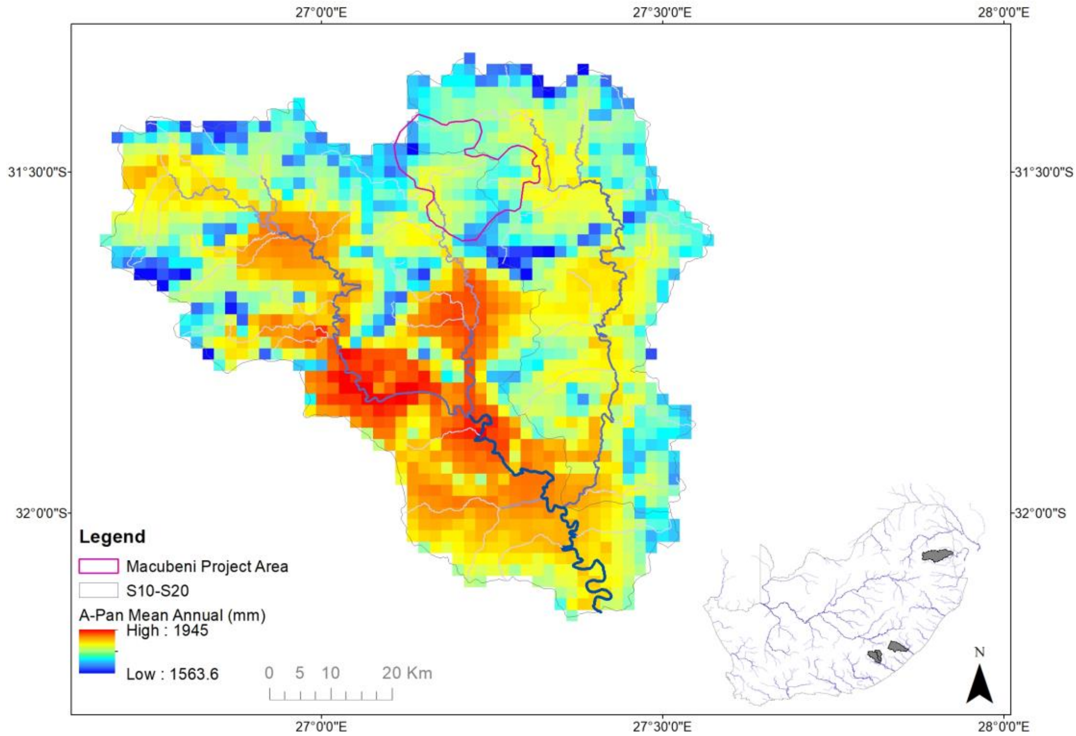


Figure 1-12 Potential evapotranspiration data (Mean Annual Evaporation, MAE, in mm) for White Kei catchment derived from South African Atlas of Climatology and Agrohydrology (Schulze 2007)

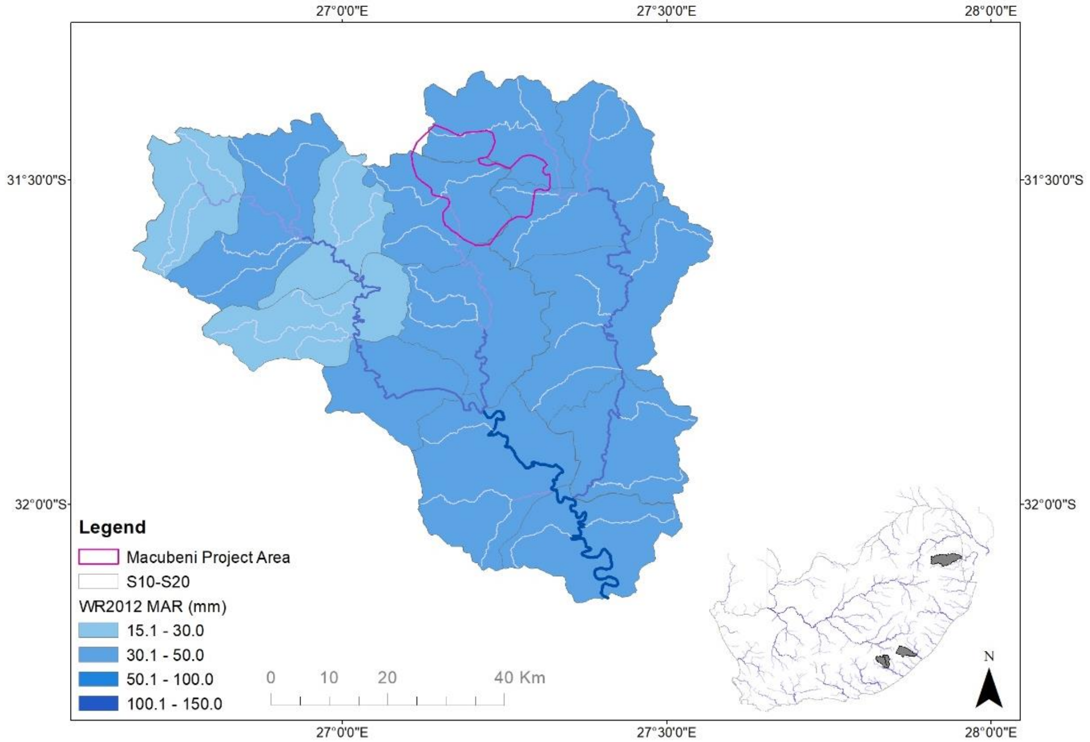


Figure 1-13 Mean annual runoff (MAR, in mm) by quaternary derived from WR2012 (Bailey and Pitman, 2015) for the White Kei catchment

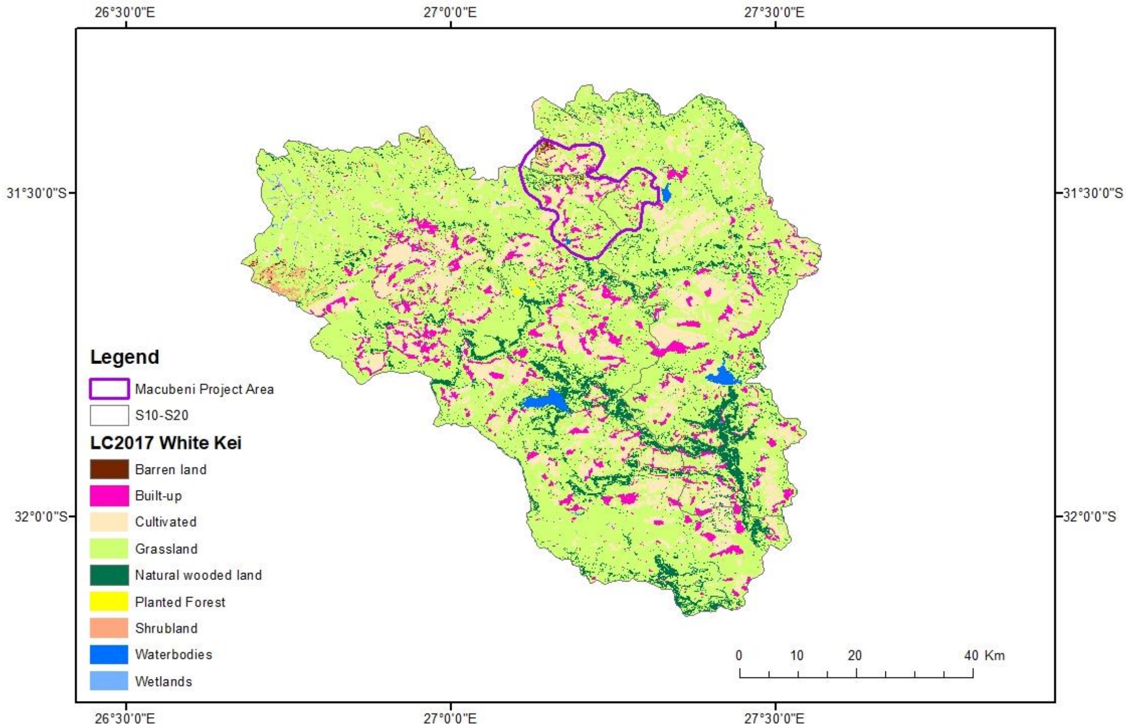


Figure 1-14 South African National land Cover (SANLC) 2017-18 (Department of Environmental Affairs, 2018) for the White Kei catchment (S10-S20)

The GEF5 project's working area consists of five villages (out of 14 in the project area). These were selected by the local leaders and the elected leadership using a number of criteria which included their proximity to each other, their varied location within the catchment, the different land-use types and activities they represent, and previous involvement with projects that included Rhodes University researchers (Sisitka and Ntshudu, 2017). The current project's participating sub-villages are Platkop, Gxojeni, Qhoboshane, Boomplaas, and Helushe (Figure 1-15).

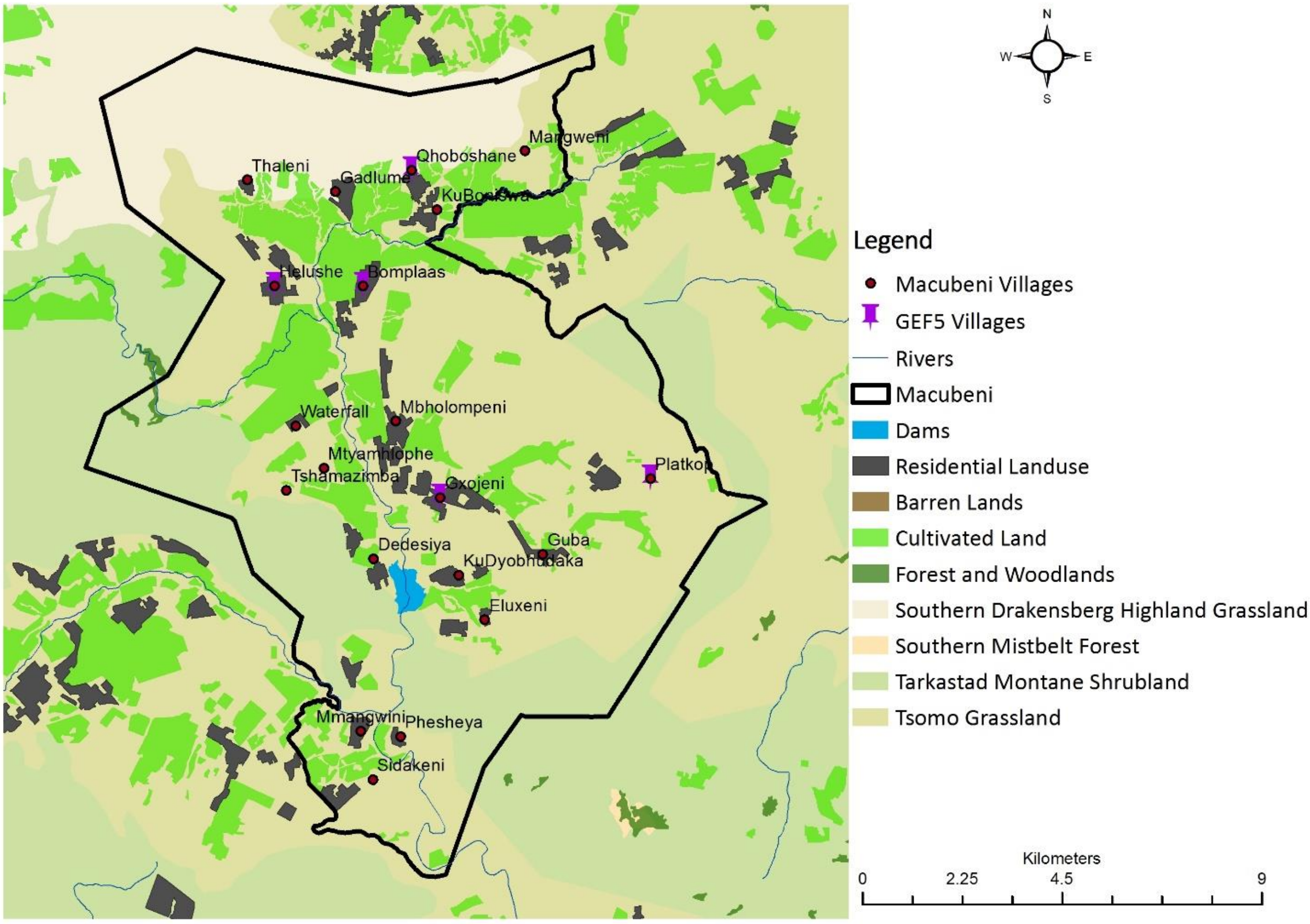


Figure 1-15 Land use and vegetation map of Machubeni sourced from the National Vegetation Map (South African National Biodiversity Institute, 2018). The Machubeni boundary is derived from the Municipal Demarcation Board (2016) dataset for eMalahleni Ward

1.3.3.1 Degraded land cover in White Kei catchment

There is a considerable level of natural vegetation degradation in the White Kei catchment according to NLC 2009 (Figure 1-16a) (South African National Biodiversity Institute, 2009). As noted under the case study background in Section 1.4.4, the two major land uses in the catchment are cultivation and built-up areas, which is also visible in the NLC 2009 that highlights the land uses and natural vegetation degraded areas (Figure 1-16b; Table 1-2). The average density of invasive plants from the NIAPS (Kotzé et al., 2010) dataset has been clipped to the White Kei catchment boundaries in Figure 1-17. The invasive alien plants are primarily located in the upper catchments and appear to be clustered around the rivers.

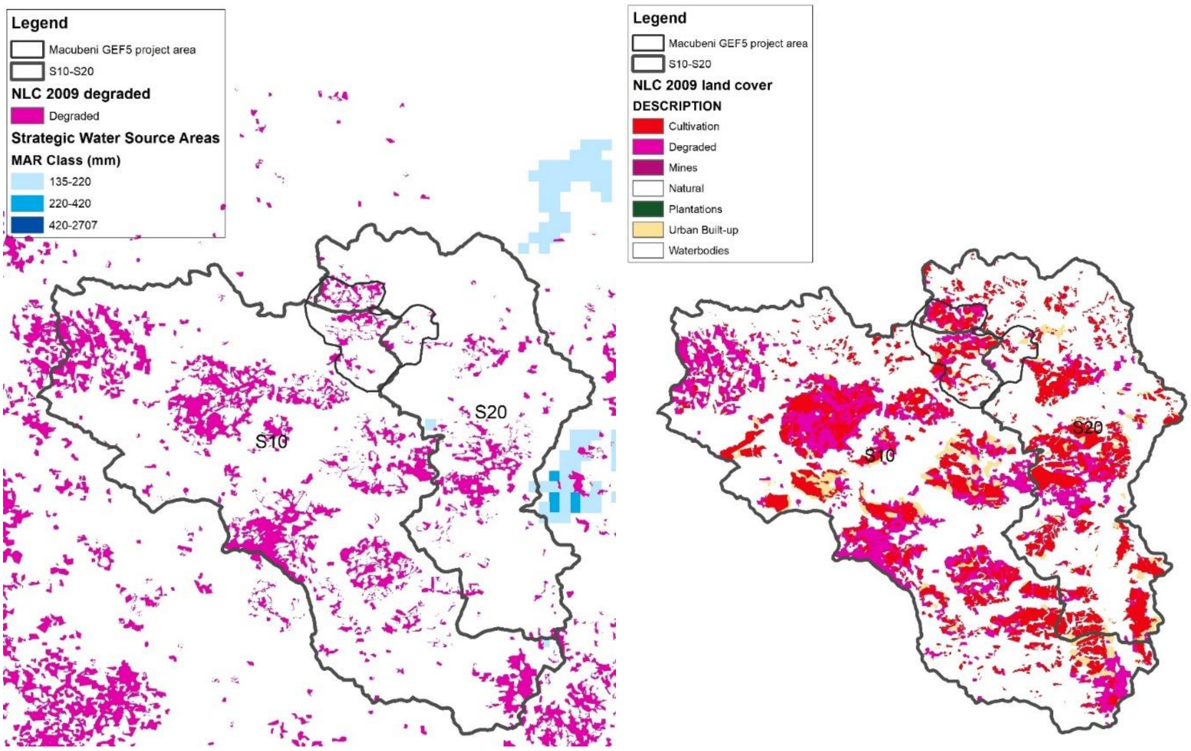


Figure 1-16 (a) Location of degraded natural vegetation areas and the surface water SWSA by MAR (Le Maitre et al., 2018a) (b) land uses derived from the National Land Cover (NLC) 2009 with transformed land categories highlighted in S10-S20 catchments

The catchment is also host to Resin Bush (*Euryops floribundus*) densification and is characterized by erosion (sheet and gully) (Shackleton and Gambiza, 2008). *Euryops floribundus* is a woody shrub species that is widely dispersed in the Eastern Cape and can grow to 2.5 m; this shrub is used by rural communities as a medicinal plant or a source of fuelwood (Shackleton and Gambiza, 2008). Sukhmani Mantel was asked to contribute towards the GEF5 project by identifying the location of *Euryops*, which was conducted using an unsupervised classification of high-resolution imagery (2 m pixel size; provided by DigitalGlobe Foundation for an MSc student in the Department of Environmental Science, Rhodes University). This classification helped identify potential areas of *Euryops* presence and the output is highlighted as red areas in Figure 1-18. The outputs have been ground-truthed by Dr Rebecca Powell (GEF5 project team manager) and the analysis estimated that a minimum of 9% of the area is covered by *Euryops*. This estimation is considered to be an underestimation of the actual area where *Euryops* is present because the imagery has shadows, which could not be classified into a land cover category and secondly, the resin bush invaded areas that are smaller than the 2 m pixel size could have been misclassified by the analysis depending on the other land covers in the pixel.

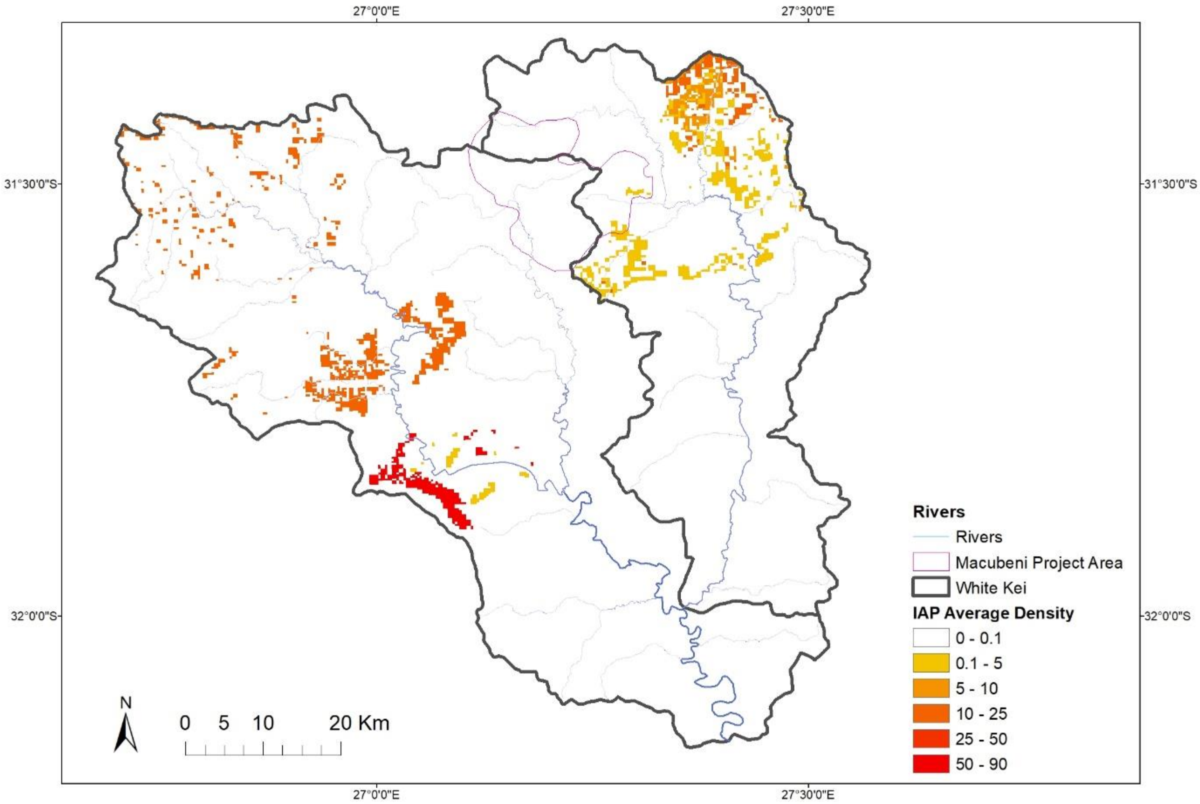


Figure 1-17 Location of invasive alien plants (NIAPS; Kotzé et al., 2010) relative to river locations in the White Kei catchment (S10-S20)

1.3.4 Case study 2: Tsitsa River catchment

The Tsitsa catchment in the upper reaches of the uMzimvubu River in the Eastern Cape (Figure 1-19) is an important focal area because of the planned Ntabelanga and Lalini dams with an approximate cost of R12.5-20 Billion under the uMzimvubu Water Project (Department of Water Affairs, 2013b). Additionally, the uMzimvubu Catchment Partnership Programme (where Tsitsa River catchment is located) is one of the flagship projects listed in the National Biodiversity Strategy and Action Plan (NBSAP) 2015-2025 (Government of South Africa, 2015), which aims to conserve the river system from source to sea through "*sustainable restoration and maintenance of the catchment area in a manner that supports economic development and job creation for local people and enhances flow of benefits from ecosystem goods and services to people and nature*". Using mapping and modelling of the catchment, Le Roux (2018) has estimated the life expectancies of the two planned dams to be 55 and 43 years (for Ntabelanga and Lalini, respectively) assuming no sediment management is applied.

This is due to various factors including erodible soils and poor management due to frequent burning, overgrazing of rangelands and abandoned croplands, according to Le Roux (2018).

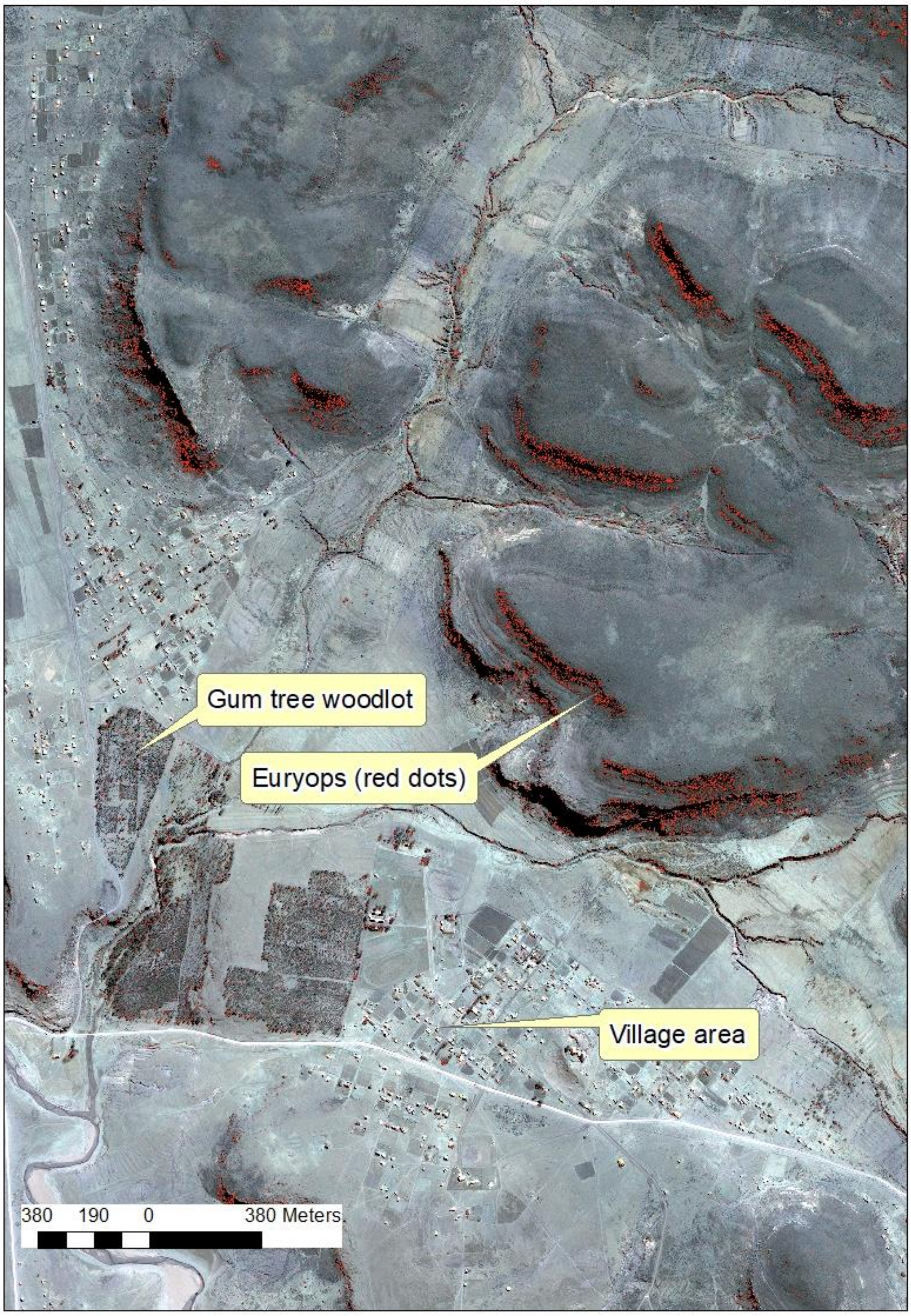


Figure 1-18 Red colour indicating an example area of *Euryops* presence in Machubeni area determined using unsupervised classification of 2 m resolution data obtained from DigitalGlobe Foundation for a Masters project under GEF5.The dark areas were classified as shadow and they could not be classified into a land cover class

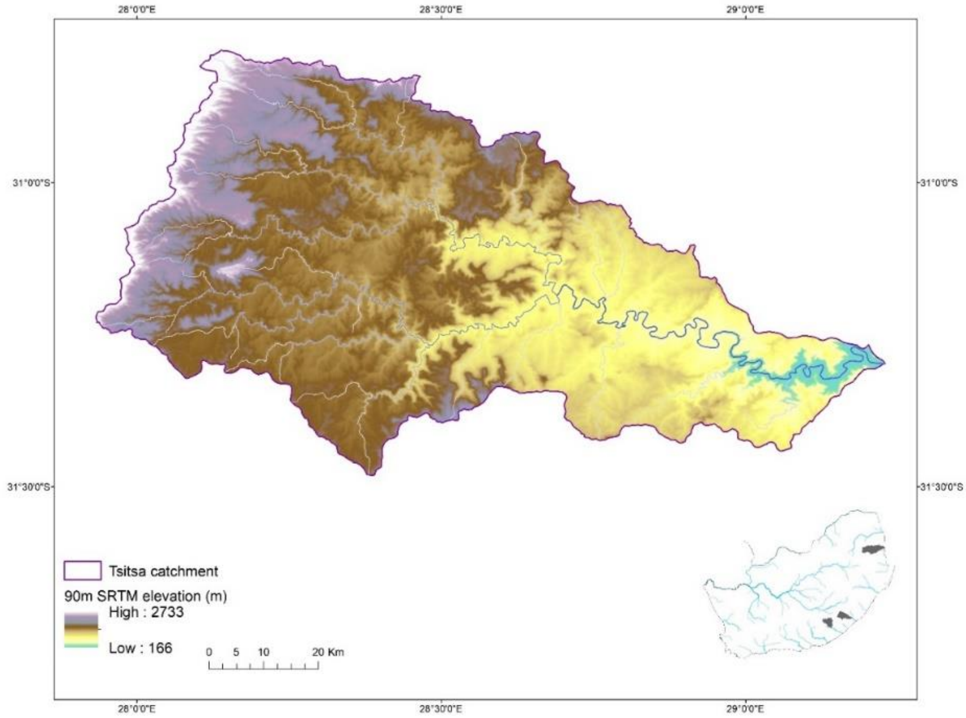


Figure 1-19 Elevation profile (90 m SRTM digital elevation model; Jarvis et al., 2008) for T35 Tsitsa River catchment

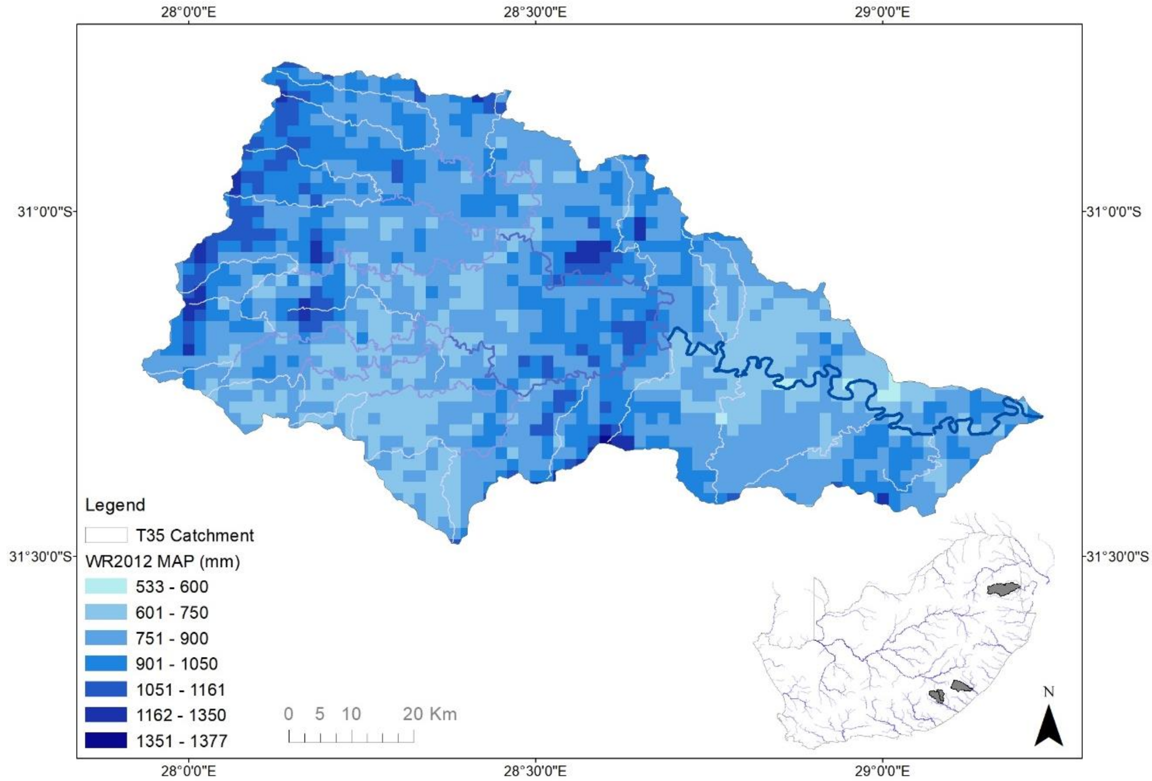


Figure 1-20 Mean annual precipitation (MAP, in mm) derived from WR2012 (Bailey and Pitman, 2015) for the Tsitsa catchment

Thus, EI is the focus of the DEA:NRM Tsitsa EI Project (originally named as Ntabelanga Lalini Ecological Infrastructure Project, NLEIP) project with a number of Rhodes University departments conducting research in the area (Fabricius, Biggs and Powell, 2016; Sigwela et al., 2017; Cockburn et al., 2018) and the catchment falls under the Water Research Commission's Green Village Lighthouse that promotes green economy in marginalised rural areas for human well-being and environmental risk reduction (Rowntree et al., 2019).

The Tsitsa EI Project is a "flagship project" where the government has recognised the value of ecological infrastructure for long-term gains of varied ecosystem services, including the capacity to retain sediments, water and nutrients on the landscape (Fabricius, Biggs and Powell, 2016). The emphasis of the Tsitsa EI Project is on natural resource management through maintenance of functional ecological infrastructure and ecosystem based restoration interventions including clearing of invasive aliens, land and wetland rehabilitations. One of the priority research themes for input into a decision support system is "Prioritization of landscapes for ecosystem repair/restoration, priority areas for investment" (Fabricius, Biggs and Powell, 2016: p. vii). This theme aligns with Aim 2 of the current project.

The Tsitsa catchment (quaternaries T35A-M) are situated in the former Transkei between Maclear Town and Qumbu, and is surrounded by small rural communities. The catchment experiences MAP between 533 and 1377 mm (Figure 1-20) and MAE of 1290 to 1770 mm (Figure 1-21). The annual runoff ranges between 79 to 320 mm for this catchment (Figure 1-22). The T35 catchment is dominated by grasslands and planted forest (plantations) in the upper reaches, while the lower areas are significantly modified by cultivation and built-up areas according to the 2017-18 SANLC (Figure 1-23; Table 1-2). The area is also a major concern due to land degradation in the past 50-100 years due to gully formation and incision of the main river channels (van der Waal and Rowntree, 2018). The dominant land uses in the catchment are both communal and private lands supporting commercial farms and plantations as well as subsistence farming (crop and livestock farming) (Bannatyne et al., 2017; Cockburn et al., 2018).

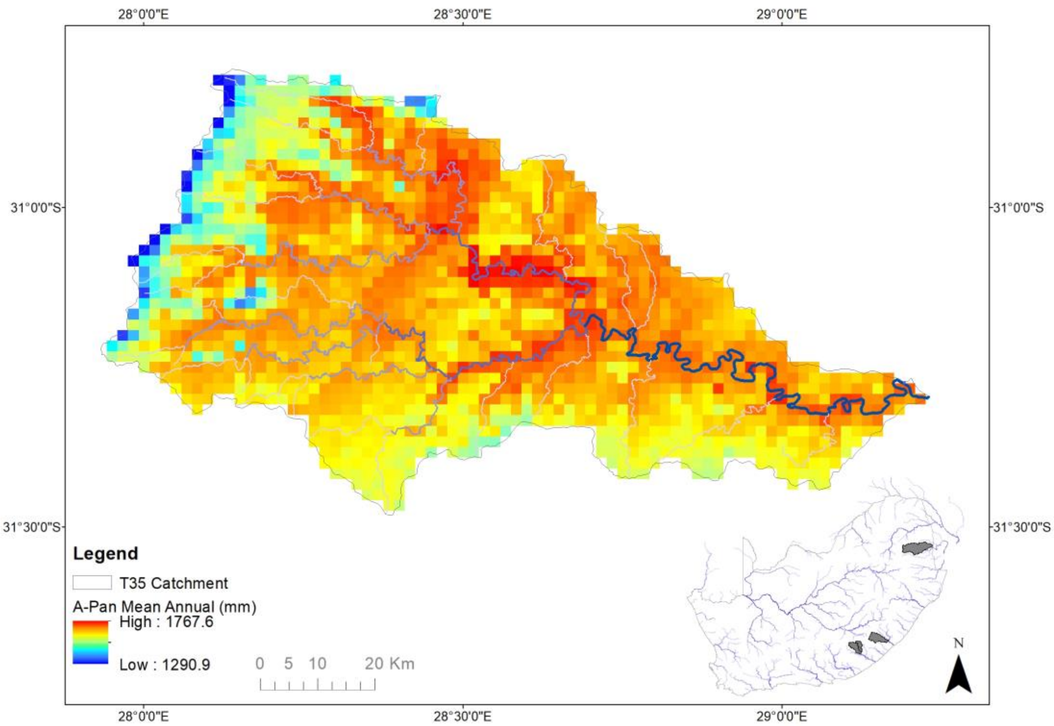


Figure 1-21 Potential evapotranspiration (MAE, in mm) for Tsitsa catchment derived from South African Atlas of Climatology and Agrohydrology (Schulze 2007)

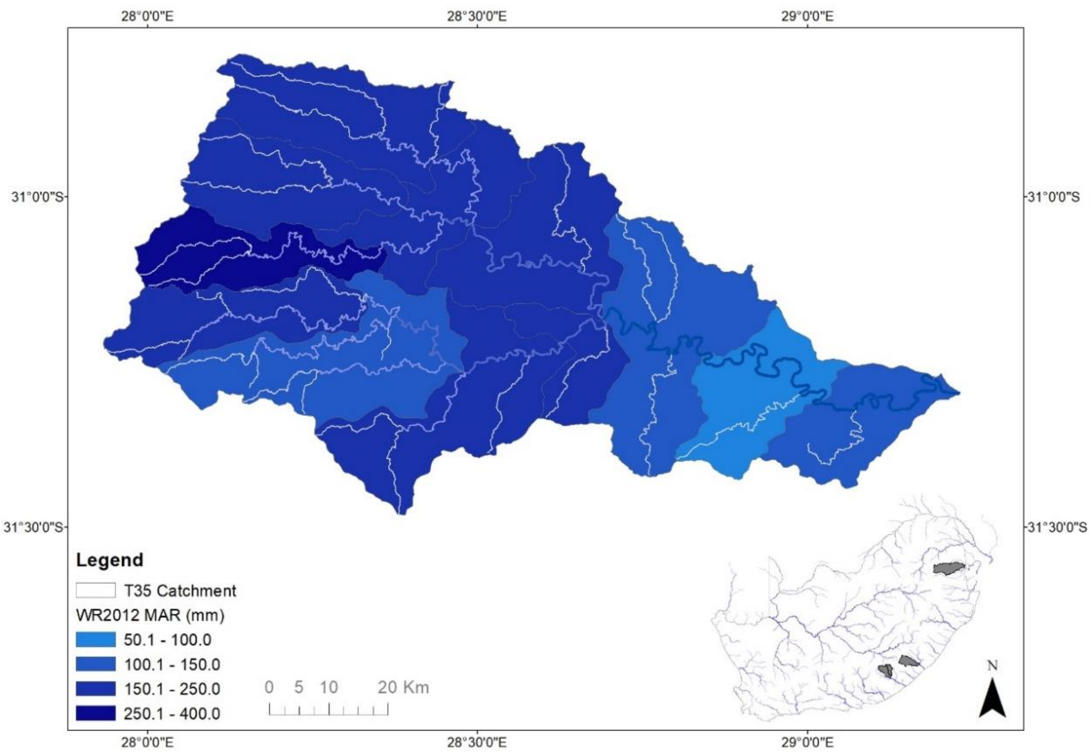


Figure 1-22 Mean annual runoff (MAR, in mm) by quaternary derived from WR2012 (Bailey and Pitman, 2015) for the Tsitsa catchment

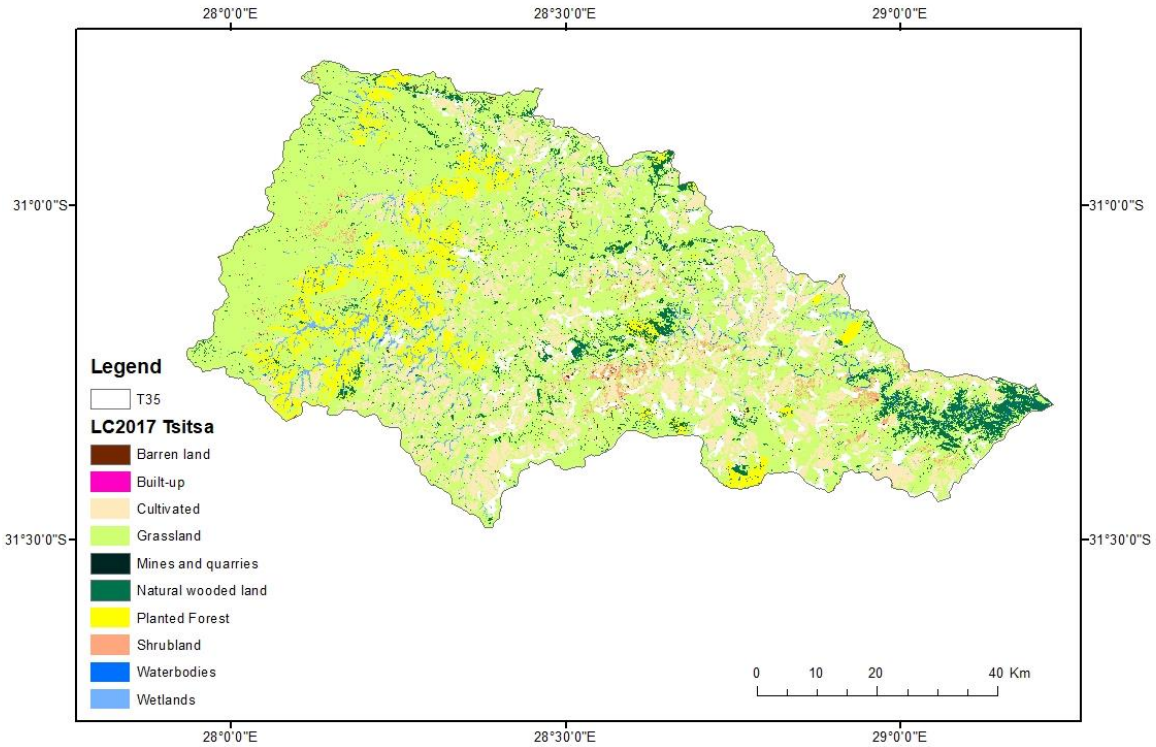


Figure 1-23 South African National land Cover (SANLC) 2017-18 (Department of Environmental Affairs, 2018) for the Tsitsa River catchment

1.3.4.1 Degraded land cover in Tsitsa River catchment

The catchment is an important Strategic Water Source Area (SWSA) in the Drakensberg (Le Maitre et al., 2018a) as can be seen in Figure 1-24a. The location of degraded natural vegetation areas recorded in the 2009 NLC is primarily in the middle and lower catchment (Figure 1-24b; Table 1-2); in addition, plantations in the upper catchment and cultivated areas throughout the catchment are important land cover modifiers.

Invasive alien plants (in addition to plantations) contribute to the land degradation in the catchment. Their presence is pervasive and significantly high throughout the catchment according to the NIAPS (Figure 1-25). Notably, although it appears that the lower catchment does not host invasive plants, this is due to an error in the NIAPS dataset that is known to the DEFF (personal communication with Dr Andrew Wannenburg).

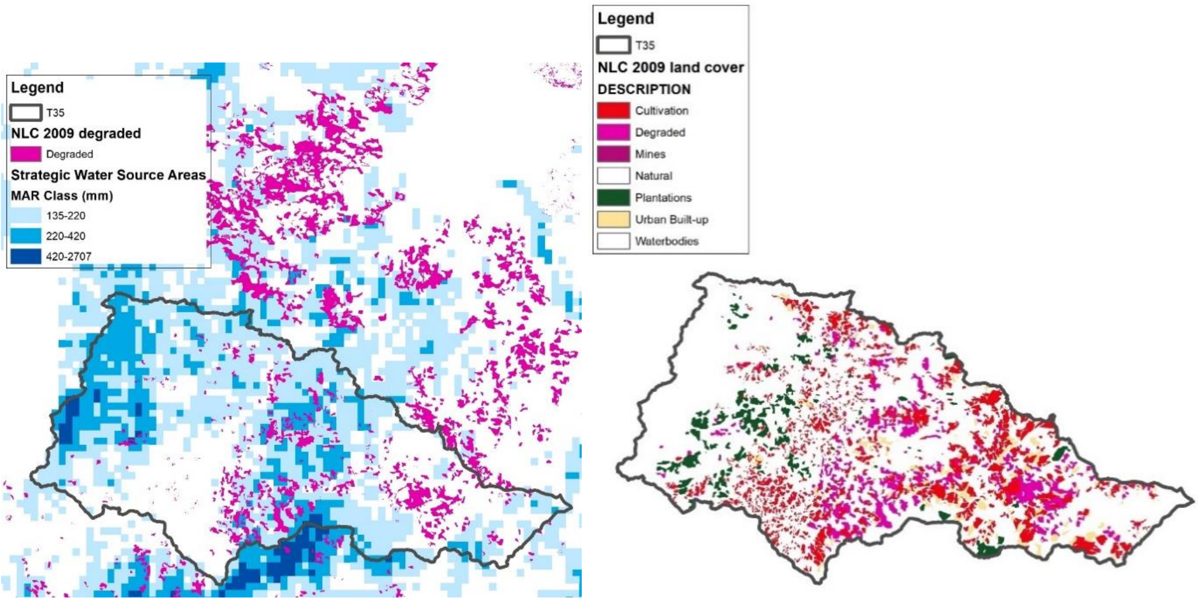


Figure 1-24 (a) Location of degraded natural vegetation areas and the surface water SWSA by MAR (Le Maitre et al., 2018a) b) land uses derived from the NLC 2009 (South African National Biodiversity Institute, 2009) with transformed land categories highlighted in the Tsitsa River catchment

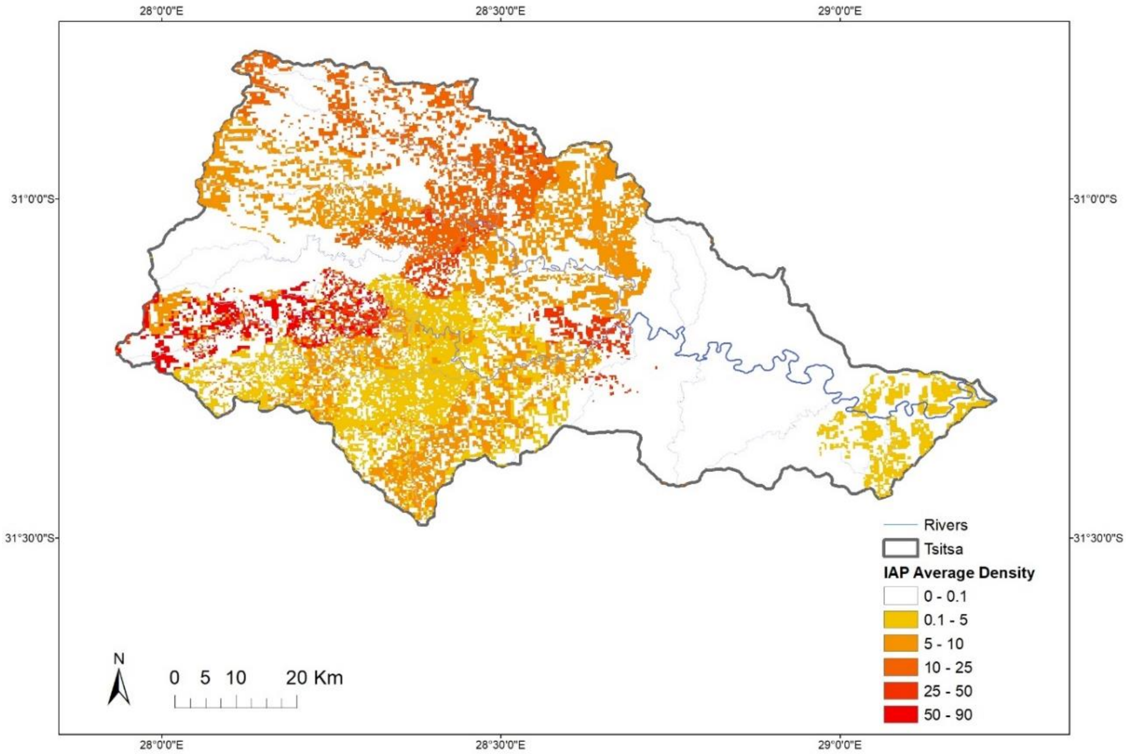


Figure 1-25 Location of invasive alien plants (NIAPS; Kotzé et al., 2010) relative to river locations in the Tsitsa catchment (T35). Note the absence of invasive plants in the lower catchment that is an error that is known to DEFF (personal communication with Dr Andrew Wannenburg)

1.3.5 Case study 3: Crocodile River catchment

The third focal catchment, Crocodile River (X21-X24), is part of the fully functional Inkomati-Usuthu Catchment Management Agency (IUCMA) in Mpumalanga (Figure 1-26); the catchment is significant due to the need to uphold international water agreements with Mozambique, in addition to being a major irrigation and forestry area (Rogers and Luton, 2016).

The Crocodile River catchment is considered one of the most ecologically important river in South Africa owing to a variety of riverine habitats from cold mountain streams to temperate Lowveld waters, resulting in the Crocodile being a biologically diverse system (Department of Water Affairs, 2013a). The Crocodile River catchment receives a wide range of annual rainfall between 346 and 1614 mm with upper catchments receiving higher rainfall amounts (Figure 1-27). The potential evaporation values range up to 2,000 mm (Figure 1-28), and the annual runoff ranges between 3.1 to 382 mm (Figure 1-29).

The current project is focusing on the upper reaches (X21) of the Crocodile due to the importance of mountainous areas in general (Wohl, 2006) and specifically in South Africa as upper reaches are of concern for the Working for Water Programme for restoring hydrological functioning in South Africa (Turpie, Marais and Blignaut, 2008). Secondly, the project set up a Pitman hydrological model for the focal catchments and due to the complexity of many water users in the lower catchment, the project team decided to limit its focus so that the benefits of restoring ecological infrastructure to flow regulation can be clearly quantified. The X21 catchment is dominated by grasslands, natural wooded areas and plantations (Figure 1-30; Table 1-2) and the area hosts three ecological Reserve sites (Figure 1-28). This is the third reason for our focus on X21 as this area is significant for long-term sustainability of the overall catchment.

1.3.5.1 Degraded land cover in Crocodile River catchment

The location of the surface area SWSAs is primarily in the upper X21 area in the catchment (Figure 1-31a) which is the focal area for the study. The degraded natural vegetation is primarily in the lower catchment, according the 2009 NLC; however, cultivation and plantations represent significant land cover transformations in the X21 catchment (Figure 1-31b). The NIAPS indicates invasive aliens are widespread across X21 (Figure 1-32) and according to Le Maitre, O'Farrell and Reyers (2007: p. 372), the equivalent economic loss (opportunity cost estimated from the cost of water for irrigation) due to flow reductions by invasive plants for the Crocodile catchment was R690 million a year.

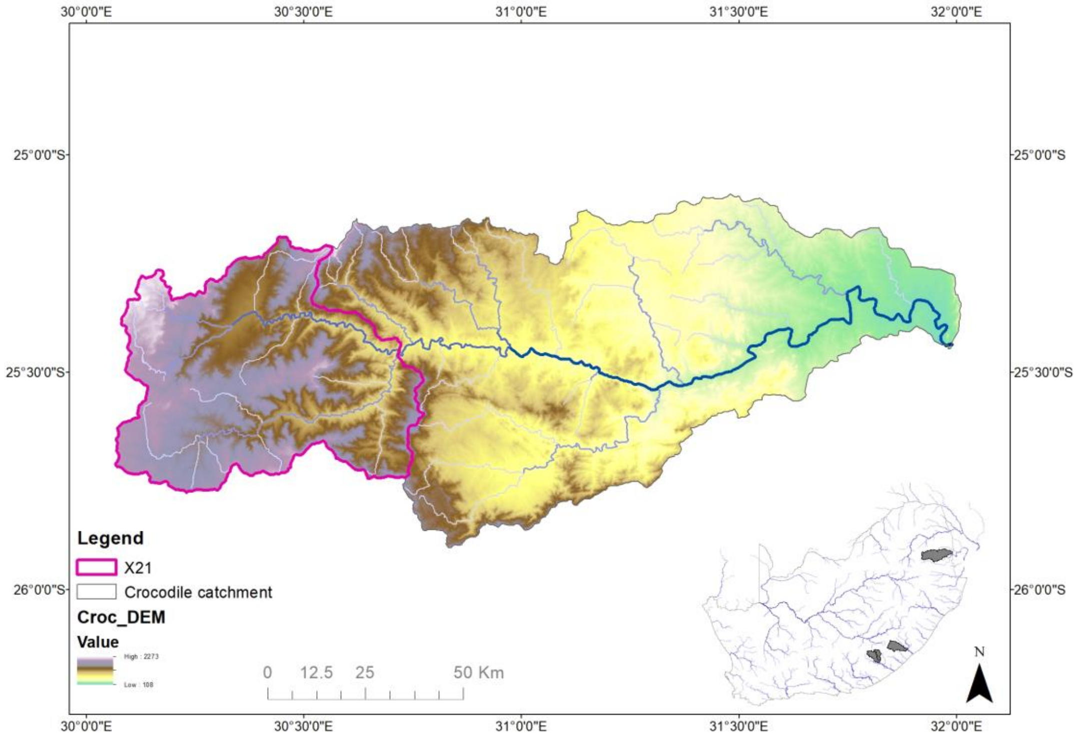


Figure 1-26 Elevation profile (90 m SRTM digital elevation model; Jarvis et al., 2008) for Crocodile River catchment (X21-X24) and the location of the X21 catchment

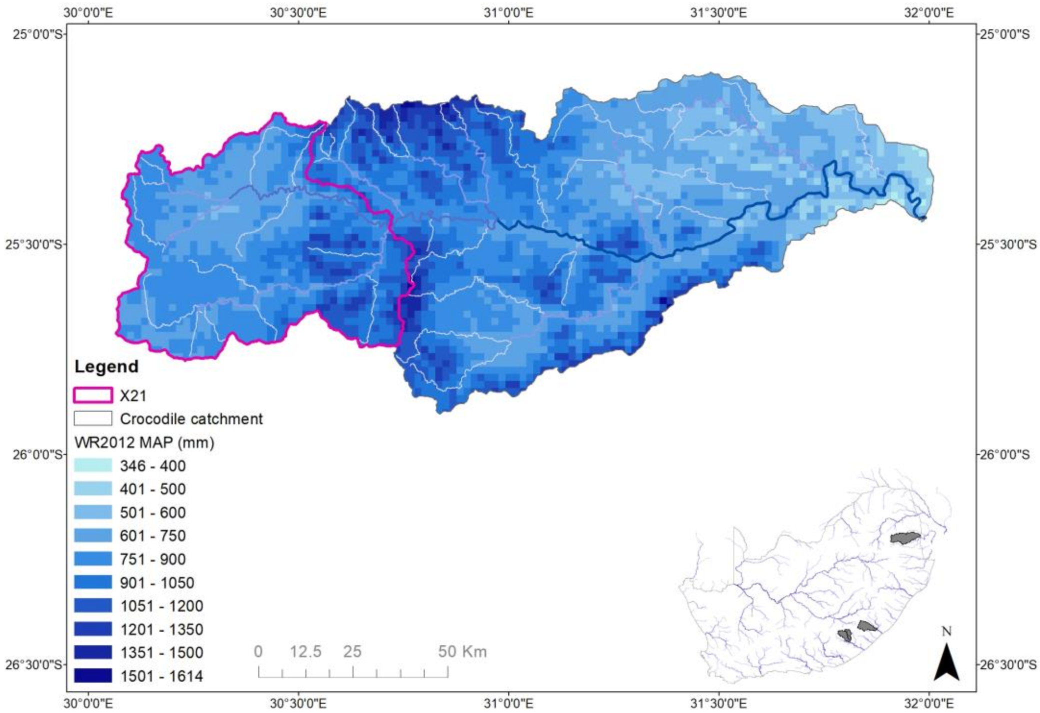


Figure 1-27 Mean annual precipitation (MAP, in mm) derived from WR2012 (Bailey and Pitman, 2015) for the Crocodile catchment

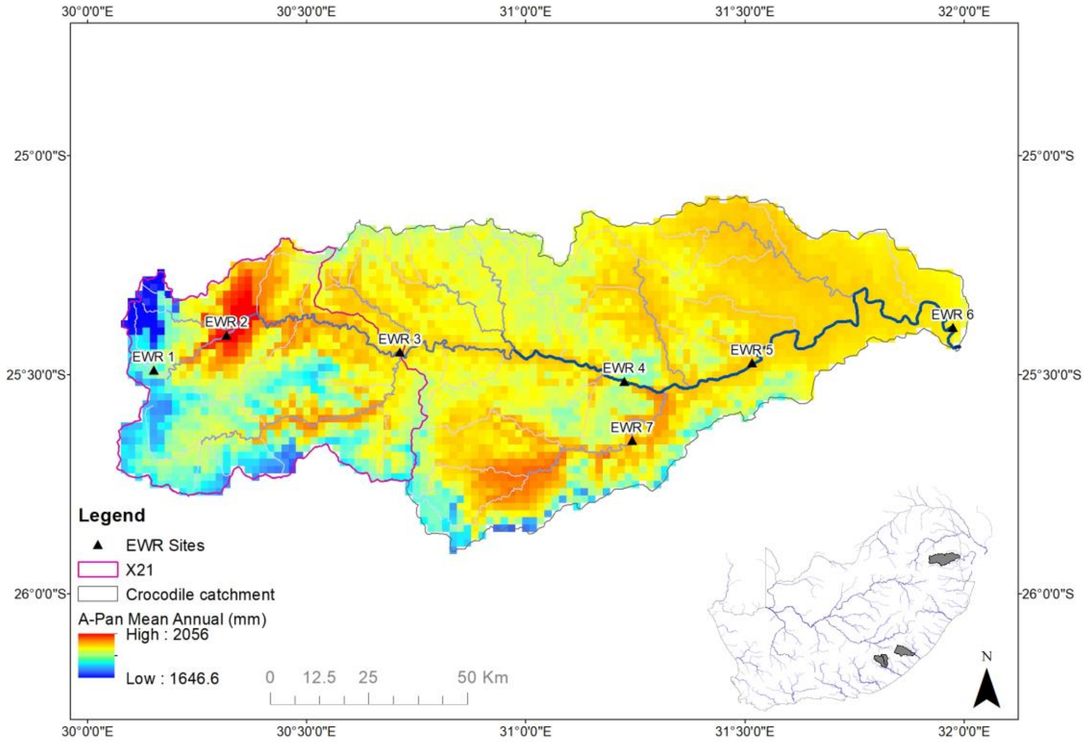


Figure 1-28 Potential evapotranspiration (MAE, in mm) for Crocodile catchment derived from South African Atlas of Climatology and Agrohydrology (Schulze 2007)

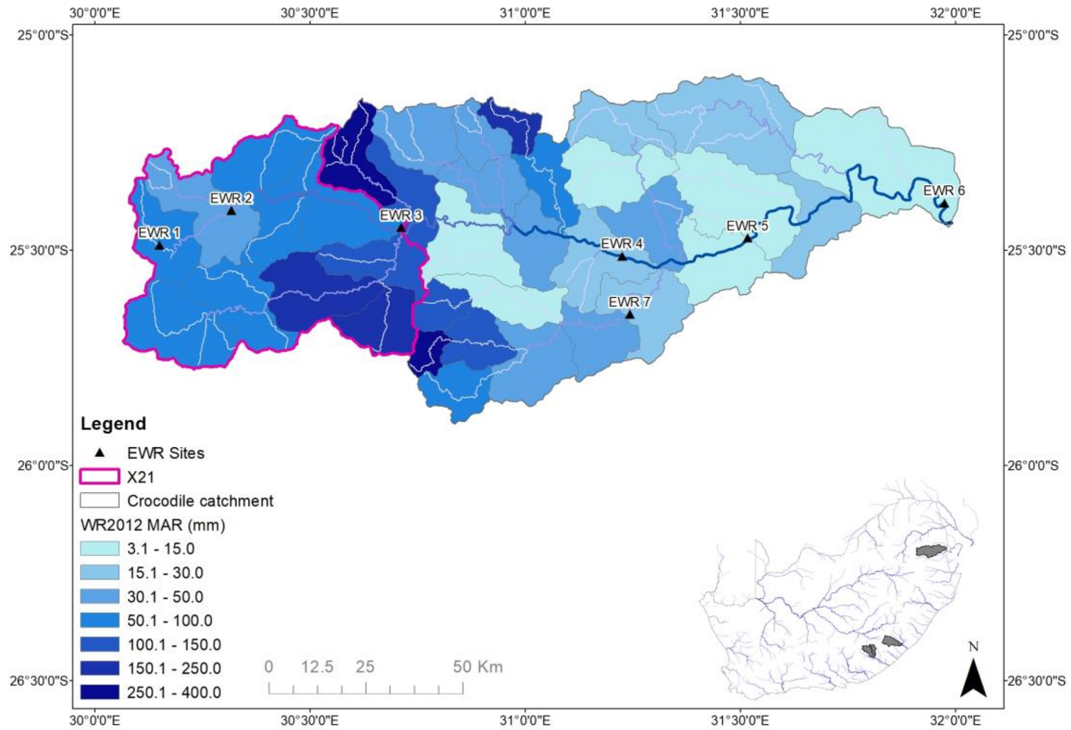


Figure 1-29 Mean annual runoff (MAR, in mm) by quaternary derived from WR2012 (Bailey and Pitman, 2015) and location of the ecological Reserve sites in the Crocodile catchment

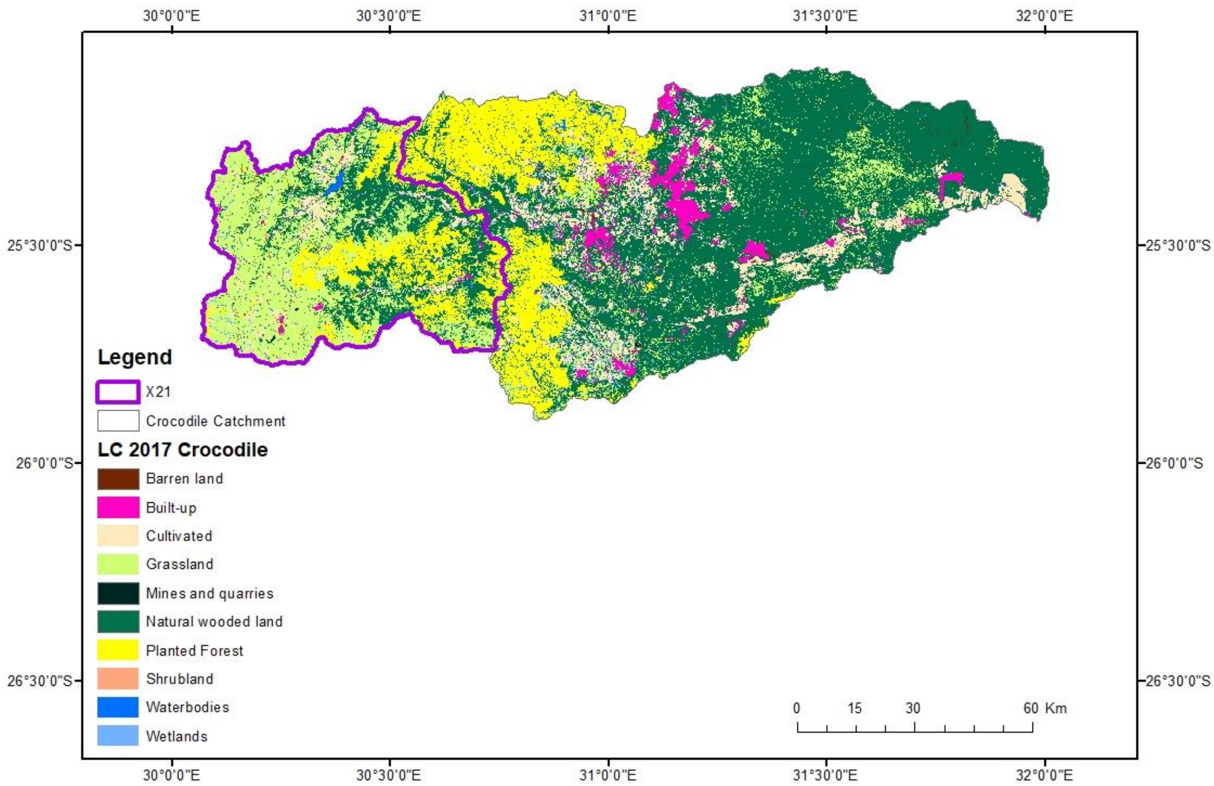


Figure 1-30 South African National land Cover (SANLC) 2017-18 (Department of Environmental Affairs, 2018) for Crocodile catchment

1.4 Structure of report and student contributions

The next three chapters address the three aims of the project and the report ends with Chapter 5 that reflects on knowledge gaps and recommendations for future research and strategic responses for maintaining and enhancing the value of services generated by EI. A significant part of the work for Chapters 3 and 4 was conducted by the two MSc students who were partially supported by the WRC grant (K5/2928):

Mr Sinetemba Xoxo

Thesis title: An assessment of ecological infrastructure role and benefit for drought mitigation in upstream rural South African catchments (Cacadu catchment as case site). The thesis has been submitted to Rhodes University for examination.

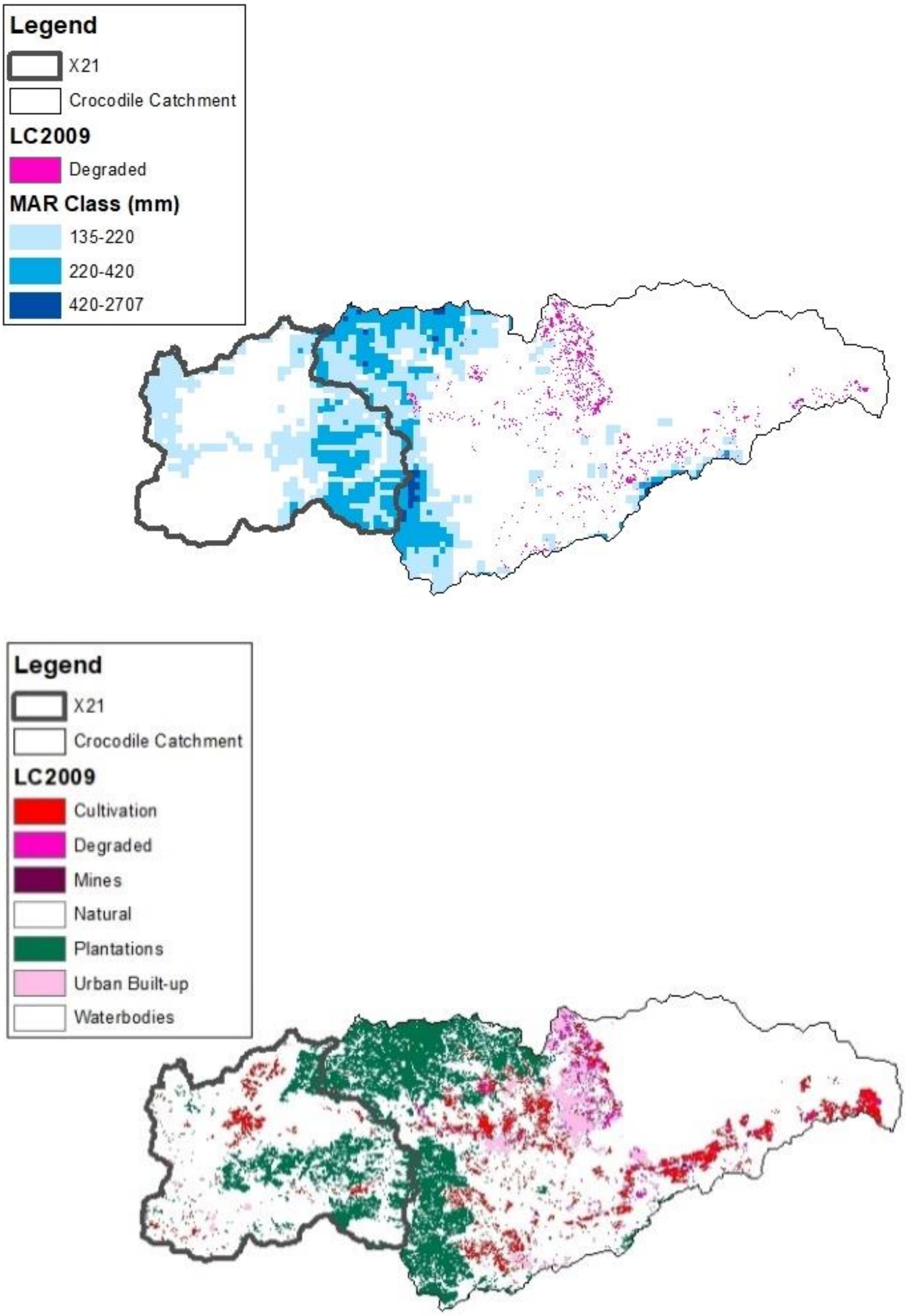


Figure 1-31 (a) Location of degraded natural vegetation areas and the SWSA by MAR (Le Maitre et al., 2018a) (b) land uses derived from the NLC 2009 (South African National Biodiversity Institute, 2009) with transformed land categories highlighted in the Crocodile catchment

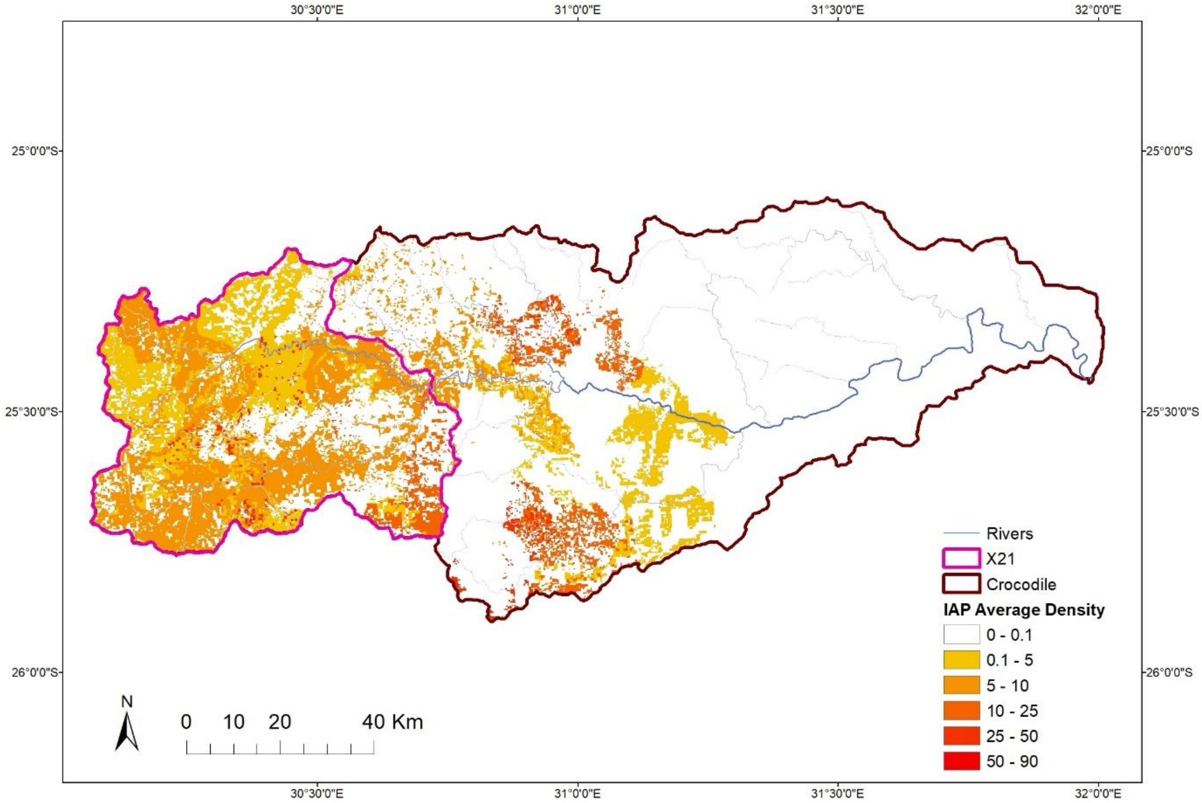


Figure 1-32 Location of invasive alien plants (NIAPS; Kotzé et al., 2010) relative to river locations in the Crocodile catchment (X21-X24).

Ms Bawinile Mahlaba

Thesis title: The assessment of degradation state in Ecological Infrastructure and prioritisation for rehabilitation and drought mitigation in the Tsitsa River Catchment. At the time of writing of this report, this thesis is still being put together and has not been submitted to Rhodes University.

This project report is presented as a summary of their theses registered through Institute for Water Research, Rhodes University. Mr Xoxo also conducted the analysis for Crocodile River catchment that is included in this report. Details of some of the work underlying the results presented in Chapters 3 and 4 can be obtained through their theses.

CHAPTER 2 ECOLOGICAL INFRASTRUCTURE FOR MITIGATING IMPACTS OF DROUGHTS (AIM 1)

This chapter addresses Aim 1 of the project: *To explain how well-managed ecological infrastructure can help to mitigate the impacts of droughts on human livelihoods and well-being and to propose strategic responses that will maintain and enhance the value of this service that people will embrace and implement*. The second component of Aim 1 is appended to Chapter 5 which provides gaps and recommendations for way forward.

2.1 Value of EI

2.1.1 Introduction

The definition and nature of ecological infrastructure (EI) and its function and role in sustaining human livelihoods and well-being by providing flows of benefits to society was briefly introduced earlier (see Chapter 1). Well-managed EI provides a wide variety of essential ecosystem service flows, with this project focusing specifically on the regulation of water flows and quality to society and the activities that sustain society (Brauman, 2015; Brauman et al., 2007) and, thus, justifies measures to protect EI (Postel and Thompson, 2005; Le Maitre et al., 2018b; Smith et al., 2015; Colvin et al., 2016). Since water is vital for all life as we know it, for growing crops and for productive rangelands, it is not surprising that hydrological services are the most economically and socially valuable services obtained from healthy catchments (Crookes et al., 2013; Bogunovic, Muñoz-Rojas and Brevik, 2018; Postel and Thompson, 2005; Brauman, 2015). The service of water provision is often seen as the primary service of catchments, but it is actually the outcome of water flow regulation, the processes by which rainwater is captured by the soils and underlying geological materials, stored as moisture or groundwater, and released slowly into springs and streams (Pokhrel et al., 2021; Brauman, 2015). The structure and state of the vegetation plays a critical role in flow regulation because interactions between vegetation, animals and soils play a critical role in determining soil porosity and, thus, its ability to absorb rainwater and minimise surface runoff during rainfall events (Le Maitre et al., 2007; Wilcox et al., 2017). The value is increased by the fact that the benefits of the flow and quality regulation are experienced by communities downstream, even being transferred between river basins by large water supply schemes (Nel, Smith and Le Maitre, 2013), or in the form of goods produced using the water flows, known as virtual water (Pahlow, Snowball and Fraser, 2015).

2.1.2 Ecological infrastructure and hydrological services: water flow regulation

> Rivers, wetlands and their catchment areas are crucial ecological infrastructure for water security, often complementing built infrastructure, but the benefits from some of these ecosystems are currently compromised by their poor ecological condition (well established). Water security can be improved through integrated management of natural resources in Strategic Water Source Areas as well as other key catchments, including protection and restoration in some cases. Skowno et al. (2019: p. 4)

South Africa's mean annual rainfall is low by global standards with an average of about 490 mm/year compared with 800 mm/year globally (DWAF, 2013). The rainfall distribution is also highly skewed geographically with more than half the country receiving <500 mm/year and only a very limited area with >1000 mm/year in the montane regions in the eastern and south-western part of South Africa (Schulze et al., 2008). South Africa's climate is highly variable and characterised by multiple-years of high rainfall and low rainfall, often leading to prolonged and severe droughts (Rouault and Richard, 2005). The low rainfall results in only about 9% of the rainfall ending up in the rivers and aquifers, while the skewed distribution results in 8% of the area of Lesotho, Swaziland and South Africa producing 50% of the mean annual runoff (MAR) (Nel et al., 2014, 2013b; WWF-SA, 2013). When adjusted to take into account key water source areas for water security, the Strategic Water Source Areas generate 50% of the mean annual runoff from 10% of the land (Le Maitre et al., 2018b).

Water flow regulation involves a suite of processes which translate rainfall events into flows of water which people can use. Rainfall typically occurs as events which last from minutes to days from the onset of the rainfall to its cessation. If there was no flow regulation, all the rainwater would flow very rapidly into streams and out of the catchment, so the streams would be dry except for short periods of floods, like the flash floods that occur in desert environments (Lytle, 2003). This does not happen in most environments because soils absorb large quantities of rain water through infiltration, the process by which it passes through the soil surface) and percolation, the process by which it moves down into and through the soil) (Beven and Germann, 1982; Beven, 2020). The soils can do this because the vegetation plays a key role: (a) providing organic matter which sustains organisms (e.g. fungi, bacteria) that decompose it into organic compounds which bind the mineral soil particles and make the soils porous; and (b) physically protecting the soil from rain drop impacts with their leafy canopy and their litter which covers the soil (Angers and Caron, 1998; Bergkamp, 1998; Lowdermilk, 1930). A wide range of animals tunnel into and turn over the soil, further increasing its porousness (Lavelle, 1997; Milton and Dean, 1992; Dean et al., 1995). The animals (vertebrates and invertebrates), fungi, bacteria and other organisms that sustain the soil functioning are collectively known as the soil biota.

Land degradation through, for example, overgrazing reduces vegetation cover, exposing soils to erosion and the formation of crusts which result in reduced rainwater infiltration and increased overland flows during storms, leading to flooding and reduced dry season flows (Turnbull, Wainwright and Brazier, 2008; Wilcox and Thurow, 2006; Mills and Fey, 2004; Le Maitre et al., 2007). The loss of the vegetation also results in the loss of organic matter that sustains the soil biota and the soil structure (O'Farrell, Donaldson and Hoffman, 2010). Reduced infiltration results in reduced soil moisture which can reduce vegetation productivity, creating a negative feedback with further overgrazing, especially during droughts. The reduction in infiltration also results in less water moving down the soil profile to replenish deep soil moisture and recharge groundwater which, in turn, reduces water storage and, thus, the groundwater discharges which sustain dry season flows (Sandström, 1998, 1995; Everson, Everson and Zuma, 2007; Hope, Jewitt and Gowing, 2004), especially during droughts, and increased stormflows which transport sediment downstream to deposit it in weirs and dams downstream. High levels of suspended and total dissolved solids in water reduce water quality and increase the treatment costs (Price and Heberling, 2018). Since rainfall is a strong driver of the productivity of South African ecosystems (Petrie et al., 2017; Donaldson et al., 2020; Archibald et al., 2009) their state is dynamic and continually changing and management needs to adapt to this to avoid degradation of the vegetation and soils (O'Reagain and Turner, 1992; Jakoby et al., 2015; Vetter, 2009; Carpenter et al., 2015; Enfors and Gordon, 2008). South Africa's soils are also prone to erosion in the SWSAs both because of the terrain and the inherent properties of the soils (Le Roux, Morgenthal and Malherbe, 2008). History has shown that the soil erosion induced by land degradation can rapidly fill dams with sediments (Le Roux, 2018; Rowntree, 2013; Rowntree, Mzobe and Van der Waal, 2012). Water security depends, therefore, on the protection and restoration of the ecosystems in these catchments.

The discussion so far has focused on the critical interactions between vegetation, soil biota and the mineral soils in creating porous soils that capture rainwater and the many other ecosystem services provided by soils (Bünemann et al., 2018; Baveye, Baveye and Gowdy, 2016). Whilst they are critical, there are other and equally important characteristics of a catchment which determine its water flow regulation capacity. These include the rainfall regime, geology and weathering, and the catchment form or geomorphology and the physical structure of the soil and underlying weathered material (McGuire et al., 2005; Geris, Tetzlaff and Soulsby, 2015; Pokhrel et al., 2021). The geology and the weathering are particularly important because they determine the water holding capacity of the soils, the volumes of groundwater that can be stored and the groundwater discharge patterns over time. Much of South Africa's geology is dominated by ancient rock formations, so the weathering can be very deep, especially in the higher rainfall regions. These characteristics were used to classify South Africa into principal aquifer types (PATs) (Colvin et al., 2007). They differ in the relationship between the degree of seasonality (evenness) of the rainfall and the evenness of the river flows from catchments dominated by the different PATs (Le Maitre and Colvin, 2008). Catchments dominated by carbonates (dolomites) sustained the greatest baseflows (e.g. dry season flows), followed by the basement complex and the extrusive aquifer types indicating that they have the greatest water storage capacity. The Karoo dykes and sills had the least catchment storage, whilst the unconsolidated formations (Kalahari sands, Coastal dune systems) store a lot of water as groundwater, but often with little discharge because of the limited relief in many of the catchments. Of course, the amount and seasonality of the rainfall overrides the effects of vegetation with evaporation accounting for all rainfall in areas with less than about 400 mm per annum (Zhang and Dawes, 2001; Hickel and Zhang, 2006), except in very wet years. This means that catchments have an inherent and finite water storage capacity which, in turn, means that people and their activities can have a significant influence on water flow regulation depending on how they manage the natural and the transformed ecosystems. The fact that the water storage and flow regulation capacity of the catchments dominated by the Karoo Group is limited, and that their soils are often highly vulnerable to the impacts of overgrazing and to soil erosion (Le Roux, Newby and Sumner, 2007; Le Roux, Morgenthal and Malherbe, 2008) means they need special protection, especially to ensure that river flows are sustained in the dry season and for as long as possible during droughts. This is especially so in the Amatola and Eastern Cape, Southern, Northern and Maloti Drakensberg SWSAs which are dominated by the Karoo Group and Extrusives. Managing or restoring the water flow regulation service entails managing the ecosystems as a whole, and limiting utilisation so that the ecosystems are maintained in a healthy and resilient state.

2.1.3 Vulnerability of rural populations

There has been a long history of land degradation through overgrazing, cultivation of marginal lands and unwise land management practices, which were aggravated by forced relocations of people to "homelands" under apartheid (Hoffman and Ashwell, 2001; Skowno et al., 2017; Hoffman et al., 2018; Hoffman and Todd, 2000; Sigwela et al., 2017). Land degradation and transformation has also resulted in significant losses of biodiversity from the species to the ecosystem and biome level, especially in wetlands, riverine systems and estuaries (Skowno et al., 2019a). All these factors have increased the risks to both food and water security.

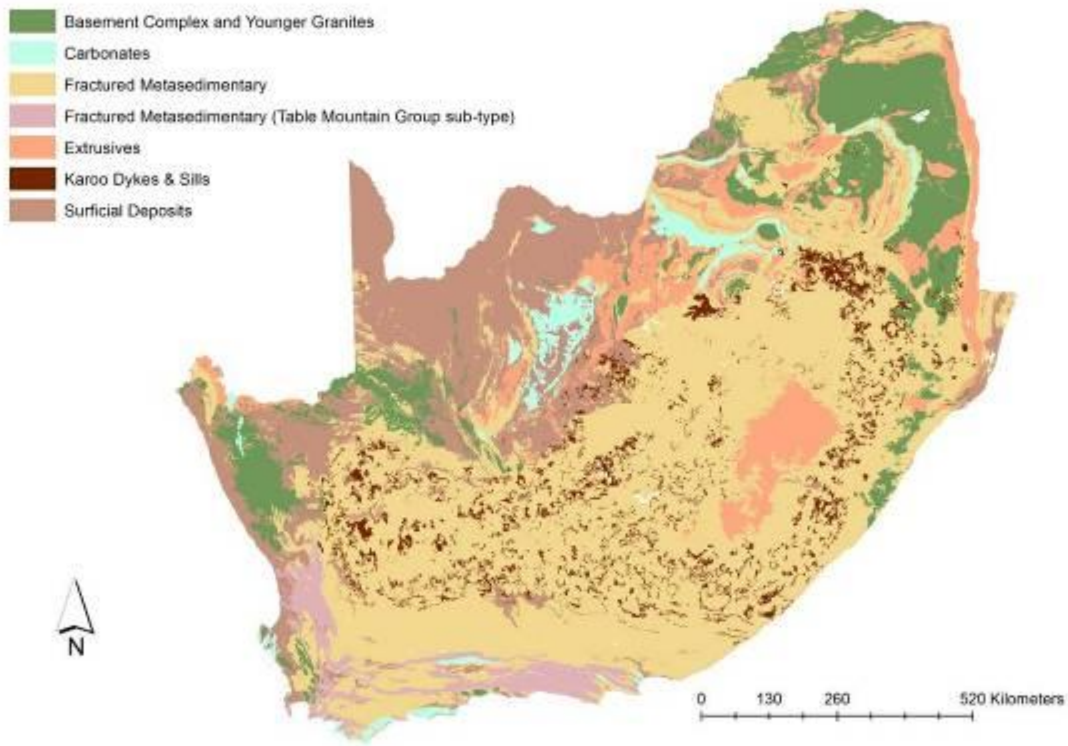


Figure 2-1 Principal aquifer types in South Africa, Lesotho and Swaziland based on the primary lithology (Le Maitre and Colvin, 2008).

The historical lack of investment in infrastructure in rural areas, especially the former homelands, has resulted in rural populations who depend heavily on the ability of these degraded lands to deliver ecosystem services (Selomane et al., 2015; Balbi et al., 2019; Rasmussen et al., 2021; Quinn et al., 2011; Sigwela et al., 2017). These communities are exposed to significant risks because vegetation and land degradation has compromised service delivery (Shackleton, Shackleton and Cousins, 2001; Shackleton et al., 2007). This is important because census data for these rural communities indicates a high dependence on water from springs and rivers which are more likely to stop flowing in the dry season. These impacts are not just local, they can affect communities downstream, sometimes far downstream of the source catchment. All these provide a strong motivation for investment in land restoration and improved land management practices (Blignaut et al., 2008, 2010; Mander et al., 2017; Blanchard, Vira and Briefer, 2015). The project changes in climate for the world and for southern Africa are that the frequency and intensity of droughts is likely to increase (Hoffman et al., 2009; Seymour and Desmet, 2009; Pokhrel et al., 2021), so society needs to begin adapting to meet these challenges (Ziervogel et al., 2014; DEA, 2015; O'Farrell et al., 2009), including prioritising the restoration of the water flow regulation functions of its SWSAs, both for surface and groundwater (Le Maitre et al., 2018b).

2.1.4 A global perspective on human impact on nature and nature's impacts on humans

The current pandemic has disrupted lives, livelihoods and global, national and regional economies and has also coincided with a number of events that have reinforced the message that humans are changing the planet. There is no doubt now that society is living in a new geological era, called the Anthropocene because of the unmistakeable human signature on planetary processes (Steffen et al., 2016, 2011a; b). The latest projections for climate change are that temperatures will continue to rise, rainfall patterns will continue to change and that extreme events will become more frequent and severe. The planet is shifting out of the climate space that was the basis for the development of modern civilisation and the massive population growth over the past 60 years or so (IPCC, 2014). Global mean temperature rise is likely to exceed the 2°C threshold for global warming (IPCC, 2014) agreed in the Paris Accord.

In parallel, a series of studies have found that the earth's capacity to deliver the ecosystem services humanity requires is being exceeded (Rockström et al., 2009; Bogardi, Fekete and Vörösmarty, 2013). South Africa is no exception and is also living beyond the limits of what the country (including Lesotho and Swaziland in the case of water) can provide sustainably (Cole, Bailey and New, 2014, 2017) (Figure 2-2). At the same time, the failure to achieve the acceptable standards of human welfare and well-being (Raworth, 2012; Dearing et al., 2014) is evident in the assessments of the failure to achieve the Millennium Development Goals and also the slow progress towards the Sustainable Development Goals (Roche, Bain and Cumming, 2017; Leal Filho et al., 2020; Selomane et al., 2015), even before the advent of Covid-19 caused major economic disruptions. Reports and papers now emerging from the international Panel on Biodiversity and Ecosystem Services assessments confirm that ecosystem services, nature's benefits to people, are declining and in jeopardy (Lovejoy, 2019; Díaz et al., 2019, 2018). This is strongly linked to the ongoing declines in the biodiversity which underpins ecosystem functions and resilience, and the delivery of ecosystem services (Harrison et al., 2018; Isbell et al., 2015; Shackleton and Shackleton, 2012; IPBES, 2019; Estes et al., 2011; Chaplin-Kramer et al., 2019). The loss of biodiversity does not only affect human welfare, it also affects human health. Recent research has emphasised the vital and manifold linkages between biodiversity, ecosystem services and human physical and mental health (Roe, 2019; Bratman et al., 2019; Whitmee et al., 2015; Sandifer, Sutton-Grier and Ward, 2015; Aronson, Blatt and Aronson, 2016; Stephens and Athias, 2015; Schmeller, Courchamp and Killeen, 2020).

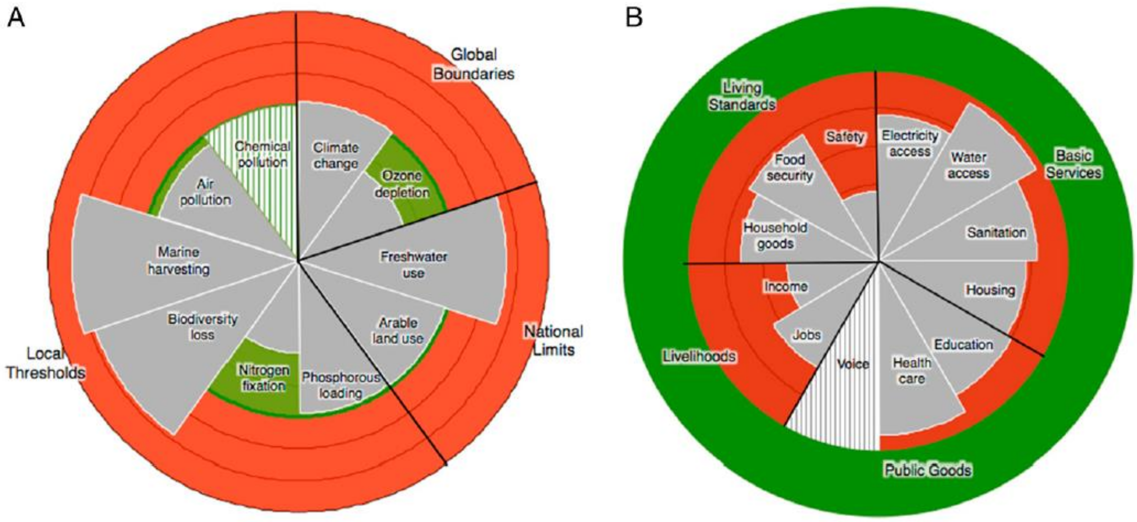


Figure 2-2 A national-level assessment of the potential for inclusive sustainable development in South Africa. The boundaries of the safe and just space are in green and red for (A) environmental stress and (B) social deprivation (B). The grey triangles measure where South Africa is on each measure using a percentage scale with 0 at the centre and 100% at the boundary. Stripes are for indicators that must still be calculated. Also shown in black lines are the three types of environmental boundaries (A) and the four social domains (B).

The evidence that human appropriation and use of natural resources is exceeding global limits, and the warning signs in the occurrence of extreme weather patterns, together with the growing magnitude of human disasters, suffering and loss of life are not only a concern for governments (UNISDR, 2015), they are a growing concern for the private sector (WEF, 2020; World Economic Forum, 2020; CCSF, 2016; Swiss Re Institute, 2020). There is an urgent need to change the development course that society is on, and to invest in restoring the earth so that it can remain resilient in the face of climate change and provide the resources needs for humanity. Concern about the lack of investment in restoration motivated the UN to declare 2021-2030 the decade of restoration (Aronson et al., 2020; Fischer et al., 2021)[1]. A number of reviews in the past decade have confirmed that ecosystem restoration and other actions to address climate change deliver benefits that outweigh the costs (Dasgupta, 2010; Sukhdev et al., 2010; Ring et al., 2010; Stern, 2016; Arrow et al., 2013; Dasgupta, 2021). While this may be true, is it necessarily true of developing countries such as South Africa? What benefits does restoration provide and who are the beneficiaries? The next section presents data from a recent assessment of the monetary value of ecosystem services in South Africa and the following section reviews restoration studies to assess the benefits and the beneficiaries.

[1] https://www.decadeonrestoration.org/

2.1.5 The value of EI in South Africa

Many of the benefits of EI and its restoration are not amenable to being converted to monetary values although they may be vital for human well-being, particularly those that are called cultural or, more accurately, life-fulfilling services (Daily, 1997; Daily et al., 2000). However, decision makers often prefer to consider only the monetary value so this section focuses on the monetary value. A recent review has found that the value of the monetisable ecosystem services in South Africa comes to about R275 billion per annum (Turpie et al., 2017), with the following contributions from the different kinds of services (annual values):

- Production
  - Fodder from natural rangelands R39.76 billion
  - Harvested natural resources (inland, estuarine and coastal) R43.3 billion
- Cultural
  - Tourism (natural attractions) R25.2 billion
  - Biodiversity existence value R6.5 billion
- Regulating services
  - Carbon storage R40.7 billion
  - Pollination R6.9 billion
  - Agricultural pest control R2.1 billion
  - Estuary nursery value R0.8 billion (58% of potential if in good condition)
  - Erosion control by vegetation R2.1 billion (R27/ha for untransformed natural areas)
  - Flood regulation (vegetation facilitating infiltration) R52.3 billion
  - Wetland flood attenuation R3.5 billion
  - Water quality amelioration (natural buffers) R9 billion

It is clear from these estimates that the monetary value of ecosystem services is substantial. The services relating to water flow regulation were valued at R66.8 billion per year. No value was estimated for water production as it was argued that the water yield would be the same with the catchments under concrete so what needed to be considered was the benefits of flow regulation for water supply through: erosion control (dam sedimentation), flow regulation (infiltration, recharge) and flood attenuation (Turpie et al., 2017). While this is logical, water is the basis for life and for the production of the food, fibre and other natural productions that sustains the economy so a value for water production would have provided a more complete picture.

A similar assessment using internationally derived values for ecosystem services estimated that ecosystem service values in 1990 were USD675 billion per year compared with USD610 billion in 2014, indicating a loss of USD65 billion (10%) over that time period due the loss of natural land cover, which does not account for land degradation. Much of the degradation of South Africa’s natural vegetation occurred prior to 1990 (Hoffman and Todd, 2000), indicating that the total losses of ecosystem benefits could be substantial. The reduction in the value of the nursery services of estuaries due to degradation though various factors including sedimentation and altered water inflows is substantial at 42% (Turpie et al., 2002, 2017; Skowno et al., 2019a). Unfortunately there weren't any suitable data to allow for estimates of the loss of benefits for dryland and riverine or wetland environments due to vegetation and soil degradation but they too are likely to be substantial.

An assessment of water erosion risk at a national scale found that about 61 million ha (50% of the country) has a moderate to high risk (Le Roux, Morgenthal and Malherbe, 2008). More than 91 million ha (75%) had a very low to low actual erosion rate, while more than 21 million ha (20%) was already losing soil at a rate >10 tons per ha per year, mainly in the Eastern Cape (EC) and KwaZulu-Natal (KZN). More than 36 million ha was at a high risk of water erosion unless the vegetation was properly maintained and managed, also mainly located in these two provinces and Mpumalanga. The EC and KZN provinces also have among the highest ecosystem service values per ha (Turpie et al., 2017), which suggests that there are already significant losses of benefits in these provinces. They are also provinces where there are extensive and often dense rural populations who depend on these services as noted earlier. The national biodiversity assessment has also found that riverine and wetland ecosystems are the most modified and transformed ecosystems in the country (Skowno et al., 2019a), a dire state of affairs considering how critical those systems are for delivering high quality water for human uses.

This brief assessment shows that the monetary value of the benefits of EI are substantial, but are they sufficient to justify the expense of restoration?

2.1.6 Does restoration pay and who benefits?

With this as background, this section attempts to address the questions posed earlier based on a recent review of restoration studies carried out in South Africa.

A recent WRC project in uMngeni River catchment (which contributes 11% to South Africa's GDP) identified where restoration of EI should be focused for long-term water security (Jewitt et al., 2020). Three (out of 10) important lessons from the project are noted here for their relevance to our study as support for ecological infrastructure:

- *Lesson 2. Investing in Ecological Infrastructure enhances catchment water security*: Clearing invasive aliens in the upstream catchment was estimated to be able to provide 15.6 million m^3 water and it can result in significant savings (estimated pumping cost savings for the upper uMngeni of approximately R15 million per year at 2017 rates) that links to Lesson 5.

- *Lesson 5. Investing in Ecological Infrastructure is financially beneficial*: The cost of maintaining grasslands (R0.31/m^3) is much lower than for restoring degraded areas (R2.44/m^3), which has implications for long-term planning for any catchment.
- *Lesson 8: Meaningful participatory processes are the key to transformation*: Any successful change can only happens through an understanding of the local conditions and requires local people to be part of the knowledge production.

There have been many assessments of the benefits of restoration projects over the years which have generally discounted the future stream of benefits over a finite period of time and using accepted discount rates (Mander et al., 2017; Blignaut et al., 2010; Crookes et al., 2013). These have shown varying returns on investment with some calculations showing that the investments did not pay (Hosking and Preez, 2002). However, the traditional approach downplays the fact that investing in restoration of ecosystems (natural capital) will result in an increased flow of benefits that will be more resilient to the impacts of climate change and will continue forever (as far as can be foreseen based on their history) (Blignaut and Aronson, 2008; Mudavanhu et al., 2017). In economic assessments this entails changing from discounting over a fixed terms to discounting into perpetuity. This approach has recently been applied to a set of 37 published restoration studies of various kinds in South Africa, summarised for the different kinds of restoration projects and presented as the opportunity cost of not restoring (benefit flows foregone, capital loss) and through portfolio mapping (Crookes and Blignaut, 2019).

For the five projects focused on clearing single alien plant species, not clearing would result in foregone benefits (marginal values) of between –[2]R26 and –R823 per ha per year – i.e. society incurs these losses through not restoring (Crookes and Blignaut, 2019). For 14 studies involving multiple alien species the values ranged from R1 493 to –R20 515 per ha per year, i.e. from a net societal benefit for not investing to a net societal loss for not investing. Only one study indicated that investment would result in a net societal loss, but a separate analysis of this study concluded that using the biomass for electricity generation could just make it a worthwhile investment (Stafford and Blignaut, 2017; Crookes and Blignaut, 2019). The three national level studies of alien plant clearing and bush encroachment clearing generated values ranging from –R264 to –R658 per ha per year (Crookes and Blignaut, 2019).

The 10 studies of other forms of ecosystem restoration found that values ranged from R3 937 per ha per year to –R3 712 ha per year. The one study where a net loss was incurred from investment applied to statutory strip mining restoration in Namaqualand where restoration is

[2] 1 USD = R13.21

expensive and its outcomes highly uncertain (Pauw, Esler and Le Maitre, 2018; Crookes et al., 2013). Most of the other restoration projects resulted in a low benefit value because of the high inputs, with one study having a very high net benefit value because its aim is to reduce dam sedimentation (Bester, Blignaut and Crookes, 2018). The review also included the opportunity costs for 5 studies of not practicing conservation agriculture for wildlife or beef production (one was for wheat growing) and estimated values between –R1 876 and –R13 131 per ha per year (Crookes and Blignaut, 2019). The review also calculated the opportunity costs over time as the average annual opportunity costs for the different restoration systems. Non-clearing restoration averaged –R687 (±R2048) pre ha per year, which indicates that society is incurring losses, when not investing and, when this was converted to a natural capital value by discounting into perpetuity, is came to –R11 453 at a 6% discount rate and –R34 359 at 2% (Crookes and Blignaut, 2019). A portfolio analysis indicated that non-clearing restoration projects were less attractive than other investments (e.g. clearing invasive alien plants) because the more uncertain outcomes of the restoration made them more risky. A key factor that counted in favour of the IAP clearing projects was the reasonably well-known water flow benefits, and it is likely that if the water flow regulation benefits were estimated for the non-clearing restoration projects they would make them even more worthwhile. All these costs of not restoring are borne by society both locally and by those downstream who experience the loss of the benefits of restoration.

All the studies that were assessed focused on quite a narrow range of benefits and omitted benefits such as employment on the projects, raising environmental awareness and food security (Crookes and Blignaut, 2019). There are many others, including more secure livelihoods because the enhanced flow regulation improves water security and increases the resilience of ecosystems to climate change. Securing livelihoods means that people rediscover their relationships to their land and have a deeper understanding of its benefits, enhancing the sense of place and their identity as wiser users of their natural resources, critical for well-being. They are able to develop a sense of agency and a belief in their capacity to be resilient to environmental change (Brown and Westaway, 2011; Garmezy et al., 1971). In most cases, the restoration of headwater catchments in Strategic Water Source Areas, will contribute to the water security of people living far from the areas being restored (WWF-SA, 2013; Le Maitre et al., 2018b; Nel, Smith and Le Maitre, 2013; Mander et al., 2017). In this way and others, restoration also contributes to national environmental security by increasing the resilience of society and its underpinning ecosystem services to the impacts of climate change (Crookes and Blignaut, 2019). Restoration also helps to sustain the regulated flows of water that enable business to operate with confidence, particularly agriculture but also mining and electricity generation. Improved flow regulation and reduced sediment loss is also vital for the many rural communities who depend ongoing water flows because their water supply infrastructure has limited storage capacity or none at all. South Africa, like the rest of the world, has to find ways to live within its limits while creating a safe and just space for its people through inclusive and sustainable development.

2.2 Justification for targeted EI land cover types for this project

> Rivers, wetlands and their catchment areas are crucial ecological infrastructure for water security, often complementing built infrastructure, but the benefits from some of these ecosystems are currently compromised by their poor ecological condition (well established). Water security can be improved through integrated management of natural resources in Strategic Water Source Areas as well as other key catchments, including protection and restoration in some cases.
>
> Skowno et al. (2019b: p. 4)

South Africa is a megadiverse country (one of 17) that is globally acknowledged for its biodiversity (Myers et al., 2000). As a result of the nation's biodiversity, the terrestrial system is characterised by nine biomes (Rutherford, Mucina and Powrie, 2006). The focal catchments in this project primarily fall under the Grassland and Savanna biomes (Figure 2-3). These biomes have been affected by clearing for croplands and human habitation, as well as bush encroachment which is partly driven by global climate change (Skowno et al., 2019b).

South African National Biodiversity Institute (2014) promotes a range of approaches for investing in EI, including the following four that we highlight as they link with the focal EI land cover types that our project has focused on:

- Improvement of practices used for rangeland management
- Clearing invasive aliens from catchments and riparian areas
- Maintaining / restoring natural vegetation buffers in riparian zones
- Rehabilitation of wetlands

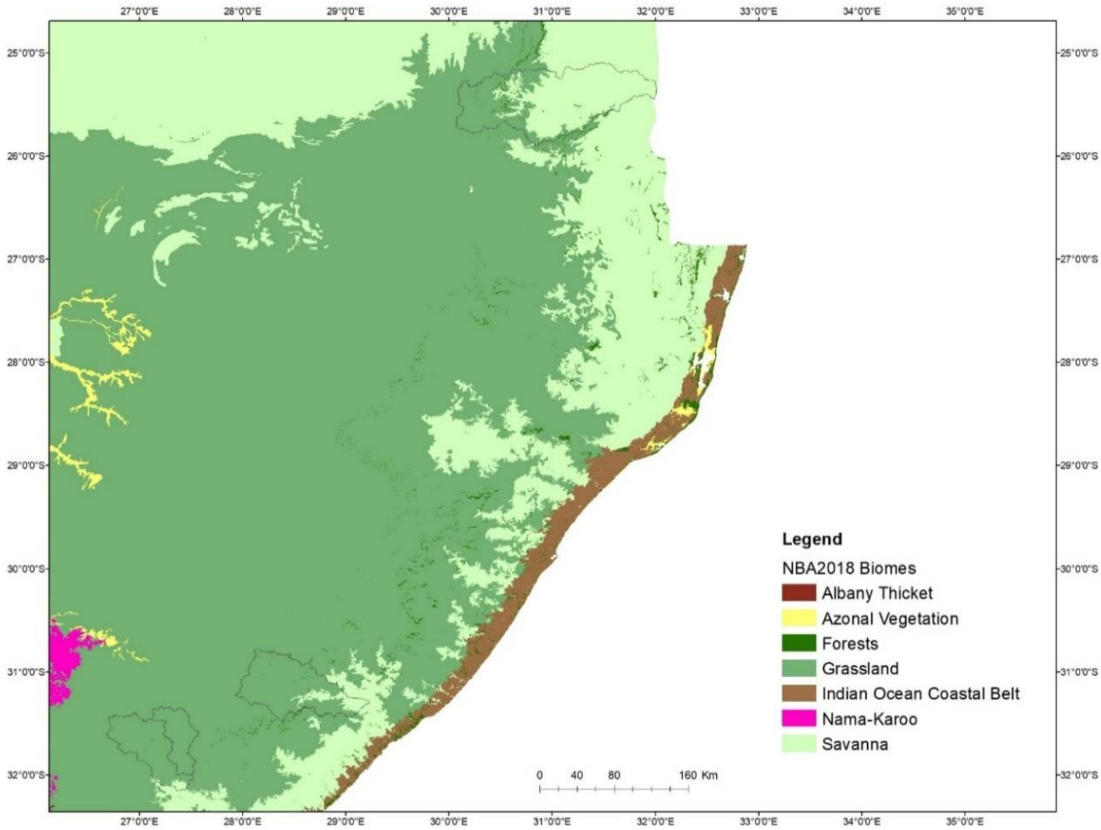


Figure 2-3 Biomes in the focal area catchments derived from the National Biodiversity Assessment (NBA) 2018

The approaches for investing in EI are also in line with the Master Plan for Water and Sanitation / NWRS2 which promotes protecting riparian and wetland buffers and critical groundwater recharge areas, rehabilitating strategic water ecosystems and protecting and maintaining freshwater ecosystem priority areas (Department of Water Affairs, 2013b). Thus, our project is focusing on four ecological infrastructure land cover types that have been selected based on their recognition by South African National Biodiversity Institute (2014) and additionally, since maintenance and restoration of these areas will support the flow regulation ecosystem services and support human well-being (Daily, 1997; Brauman et al., 2007; Brauman, 2015). These target EI land cover types are grasslands/rangelands, riparian zones, wetlands, and abandoned croplands. The last category of abandoned croplands (which is not directly mentioned by SANBI’s 2014 framework) is justified by previous research that has identified them as focal areas for invasive alien plant invasion as well as a significant cause and source for soil erosion. The sections below provide brief background information for these focal target EI types.

2.2.1 Grasslands

Natural grasslands serve as browsing and grazing areas, i.e. as rangelands for livestock and game (Scholtz et al., 2013), and they are considered to be important to indigenous communities as they provide various ecosystem services related to their livelihoods (Sigwela et al., 2017; Bengtsson et al., 2019), while many commercial producers use enhanced or artificial pastures and feedlots for finishing livestock. Bengtsson et al.'s (2019) review of ecosystem services obtained from natural grasslands in Southern Africa lists water supply and flow regulation, carbon storage, erosion control, and climate mitigation, amongst others. Soil erosion and gully formation is a significant driver of land degradation in grasslands and has been linked to human activities such as continuous grazing, frequent fires, old lands, livestock tracks and roads (Palmer and Bennett, 2013; Van der Waal and Rowntree, 2018: Figure 5). The recently released National Biodiversity Assessment (NBA) 2018 report notes that 103 ecosystem types (or 22% of 458 types) are threatened in South Africa (Skowno et al., 2019a). This assessment only includes the vegetation type which is in a (near-)natural state based on the land cover, and no assessment of degradation is conducted. Additionally, grassland is noted as one of the top three biomes (the others being Fynbos and Indian Ocean Coastal Belt) that have the highest number of threatened ecosystem types (Skowno et al., 2019b: p. 11); this status is linked to development pressure.

The future projections for grasslands is of concern, according to land cover modelling of an Eastern Cape catchment with communal farming, as they are predicted to continue to be transformed to woody plants and cultivated land by 2030, if the current trajectory of land cover change continues (Gibson et al., 2018). This also implies greater evapotranspiration and reduced water availability, which will affect the local farmers. Thus, South Africa needs to heed the call by Cumming et al. (2017) to prevent land degradation and restore degraded rangelands as an adaptive water management strategy for drought. The uMzimvubu Catchment Partnership Programme (UCPP) in the uMzimvubu River catchment is one such project that is focusing on rangeland restoration and alien plant managements (South African National Biodiversity Institute, 2019).

2.2.2 Riparian areas

Riparian zones provide various ecosystem services including water filtration, flood attenuation, sediment regulation as well as habitat for organisms; these zones comprise the lateral connectivity of the river channel with the catchment (Naiman and Décamps, 1997; Marais and Wannenburgh, 2008). Supporting research has indicated that natural vegetation presence and the amount of area covered is an important predictor of both riparian and instream freshwater integrity (Amis et al., 2007). Riparian areas are significant contributors to ecosystem function and clearing invasive aliens has been shown to improve biodiversity hosted by riparian zones (Modiba et al., 2017). These areas also provide various medicinal products, which were estimated by Turpie et al. (2010; cited in SANBI, 2019: p. 111) to represent 47% of harvested medicinal products. As riparian zones are susceptible to invasion by alien plants, various WRC projects have investigated management of these areas as contributions towards catchment management, including comparison of methods of removal that support soil processes, microbial structure, and their diversity (Everson et al., 2007, 2014; Scott-Shaw et al., 2016; Jacobs et al., 2013, 2017).

Rivers are also invasion pathways for invasive aliens, which utilise large quantities of water through transpiration and reduce streamflow (Le Maitre et al., 2020: Table 15.1 and suporting text), and are thus one of the focus areas of Working for Water (WfW). A cost-benefit analysis of clearing of invasive alien plants from riparian areas by WfW during 10 years (1996-2006) indicated an increase in streamflow of 46 million m^3 per annum and an increase in yield from dams in addition to an increase in run of river abstractions of 34.4 million m^3 per annum (Marais and Wannenburgh, 2008). Thus, the NWRS2 promotes actions such as protecting riparian and wetland buffers along with critical groundwater recharge areas, rehabilitating strategic water ecosystems, and protecting and maintaining freshwater ecosystem priority areas (Department of Water Affairs, 2013b). Day, Rountree and King (2016) have developed a useful comprehensive guide for river rehabilitation including managing for invasive aliens, flooding risks, river bank erosion, rehabilitation and flow regimes.

2.2.3 Wetlands

Wetlands have been suggested to be the "solutions for water security" (Russi et al., 2013: p. iv) as they play important roles in sediment, flow and flood regulation, as well as recharge of groundwater aquifers. A key finding of the 2018 NBA is: "Wetlands are the most threatened of all South Africa's ecosystems, with 62% of wetland ecosystem types Critically Endangered" (Van Deventer et al., 2019b: p. xii). The loss of wetlands as ecological infrastructure leads to increased landscape and sediment connectivity (van der Waal and Rowntree, 2018), increased flood frequency and severity (Rebelo et al., 2015), and reduced base flows (Poff et al., 1997; Brauman et al., 2007). A recent economic evaluation of flood attenuation by wetlands in South Africa was estimated to be around R3.5 billion annually (Turpie et al., 2017). The loss of wetlands and the associated biodiversity is also a loss for rural communities, which depend on them for resources (Schuyt, 2005). Thus, finding a balance between healthy wetlands and land use activities has been promoted as a means to protecting and restoring important ecosystem services such as water provision, flood attenuation and water flow regulation (Rebelo et al., 2015; Figure 2-4).

2.2.4 Cropland abandonment

Globally, the loss in ecosystem services and biodiversity as a result of land use has been recognised as noted in Figure 2-5 (sourced from IPBES, 2018a) that shows how increasingly intensive food production over time can eventually result in crop abandonment due to degraded soil. This end point leads to loss in ecosystem services in various dimensions including climate regulation, biodiversity, food, fibre and water retention.

In South Africa, commercially farmed fields were established and farmed during the period of massive agricultural subsidies. When the subsidies could not be sustained in the late 1980s or early 1990s they were abandoned because they were too marginal. What is of concern is that these abandoned croplands can act as foci for the spread of alien plants in addition to being a source and cause of erosion, resulting not only in loss of ecosystem services and native biodiversity, but also in the promotion of alien plant invasion (Kakembo and Rowntree, 2003; Huchzermeyer et al., 2018). Prioritisation of sustainable land management interventions that are linked to rural development and job creation has been recommended from a perspective of socio-economic, environmental and expenditure justification (von Maltitz et al., 2019). A South African study of cropland abandonment from 1950-2010 indicated various reasons behind this action including rainfall variability and droughts, no access to draught power, as well as younger individuals not being interested to pursuing this lifestyle (Blair, Shackleton and Mograbi, 2018). The abandoned areas can be hosts for invasive species and bush encroachment over time. Research by Scorer, Mantel and Palmer (2018) also found abandoned croplands (or disturbed grasslands) more prone to invasion by *Acacia* species. The study evaluated the area covered by *Acacia* over time in unimproved and disturbed grasslands using aerial imagery from four different time periods between 1958 and 2009. Figure 2-6 shows comparative example images from 1958 and 2009 for areas of unimproved grasslands and those with abandoned cultivation that show *Acacia* expanding at a faster pace in the latter situation. The reasoning is that *Acacia* saplings are expected to be cleared in areas that are continually cultivated, unlike abandoned cultivation areas. A second hypothesized reason for the lower rate of spread of *A. mearnsii* in undisturbed grassland areas is due to grass-fuelled fires that prevent *Acacia* saplings from establishing.

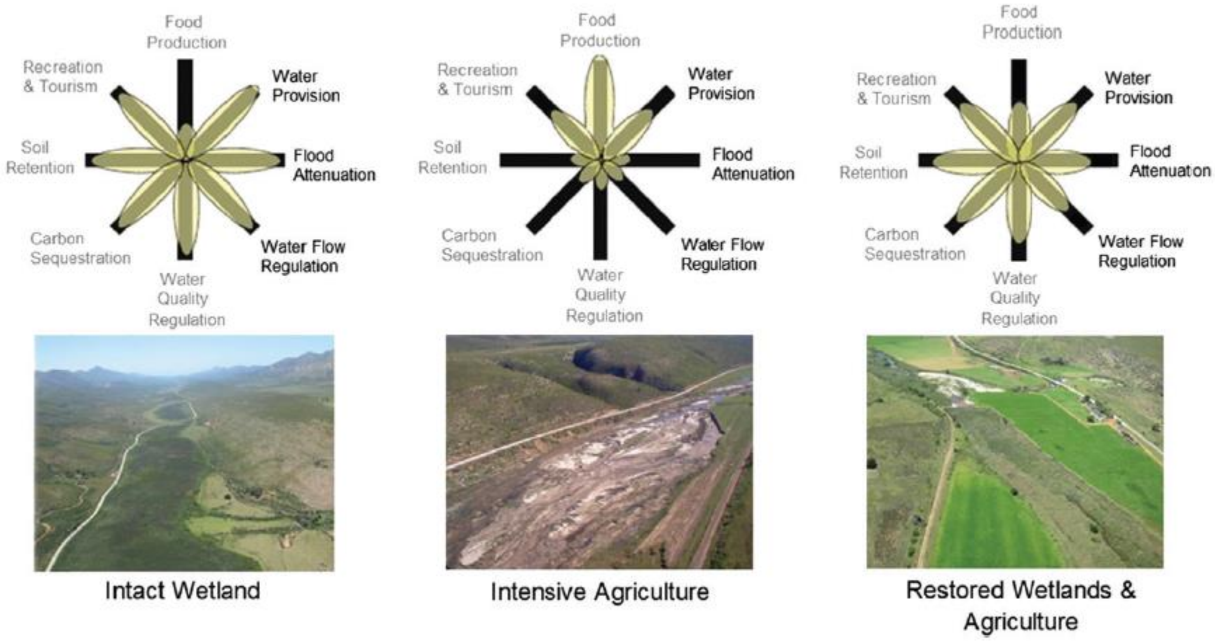


Figure 2-4 Figure from Rebelo et al. (2015) based on flower diagram conceptualised by Foley et al. (2005; Figure 2-2) comparing trade-offs between ecosystem services under various land use scenarios with left image showing a natural ecosystem with high ecosystem services in comparison to intensive agriculture (middle image) and a balance of restored wetlands along with cropland production (right image)

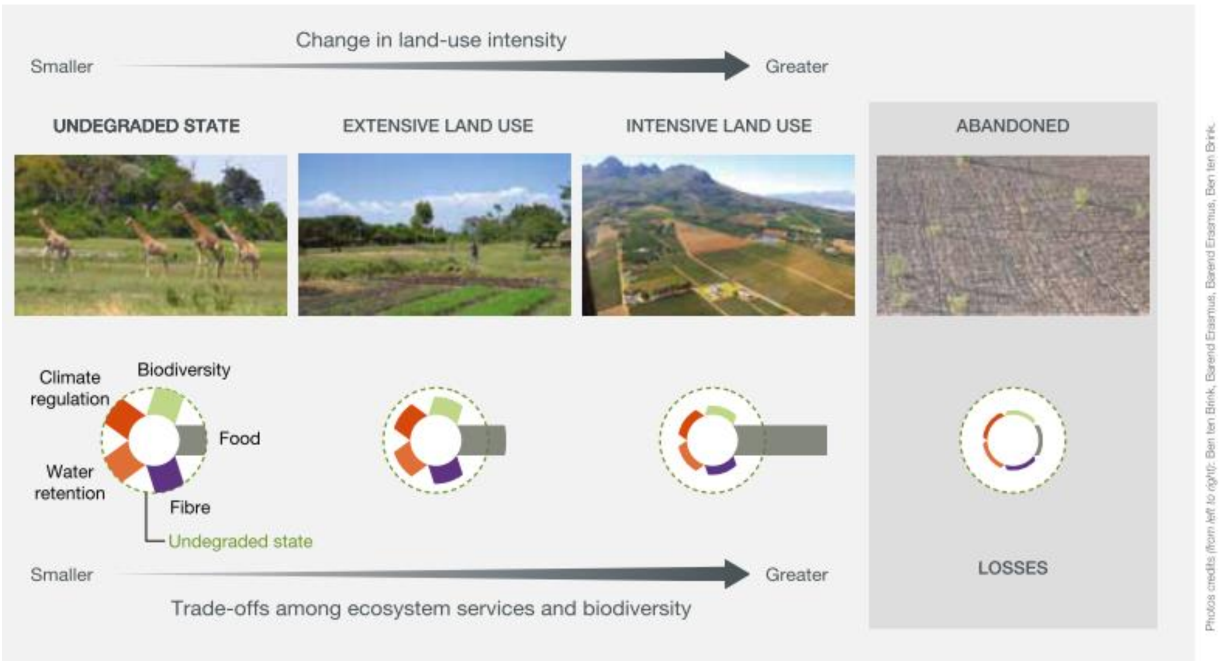


Figure 2-5 Figure SPM.3 from (IPBES, 2018a: p. 19) showing the loss in ecosystem services and biodiversity with intensive land use for food production and eventual abandonment

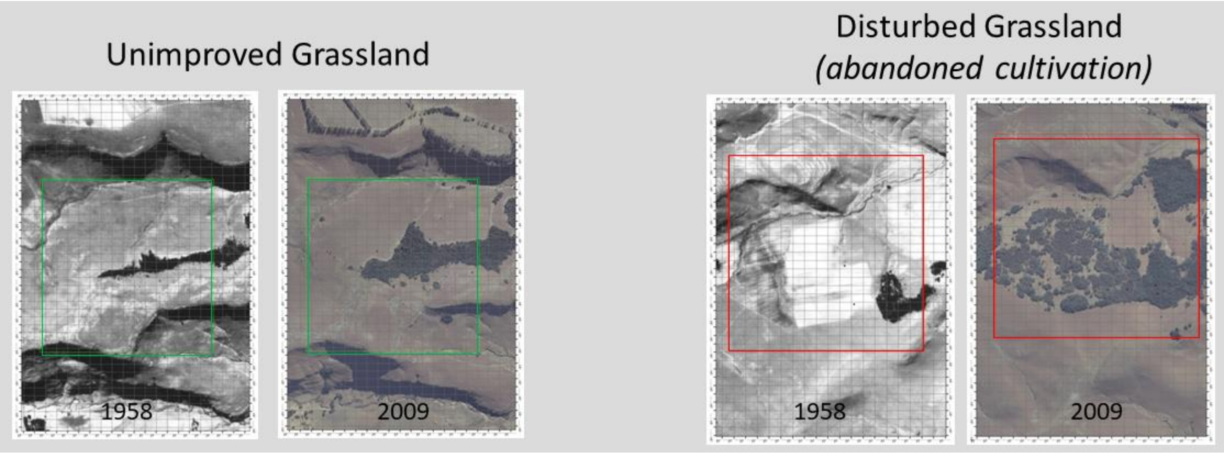


Figure 2-6 Comparison of wattle encroachment into areas of unimproved grassland (left) versus disturbed grassland where cultivation has been abandoned (right)

2.3 Response to climate change impacts on water

> Water underpins economic activity in all sectors. It is also the primary medium through which the effects of climate change will be felt in South Africa. Climate change will alter water runoff and recharge rates, and change the availability, seasonality, timing, volume and quality of water available. New risk and vulnerability studies conducted by the Department of Water and Sanitation show that all the six hydro-climatic zones — the Limpopo, Olifants and Inkomati basins; the Pongola-Umzimkulu region; the Vaal River system; the Orange River system; the Mzimvubu- Tsitsikamma region; and the Breede-Gouritz and Berg-Olifants basins — will be affected by climate change, including surface and groundwater. While climate models display a level of uncertainty, an increase in erosion and sedimentation, water pollutants, flooding and drought, among other impacts, is expected.
>
> Department of Environmental Affairs (2017a: p. 45)

South Africa has developed various policy related documents aimed at responding to climate change, including the National Climate Change Response White Paper (NCCRWP) (Department of Environmental Affairs, 2011) and has implemented a National Integrated Water Information System (NIWIS) with a drought status dashboard (http://niwis.dws.gov.za/niwis2/; accessed 20 October 2019; see Figure 2-7). The municipalities are also required to include climate change in their Integrated Development plans (Department of Environmental Affairs and SALGA, n.d.; Department of Environmental Affairs, 2017b).

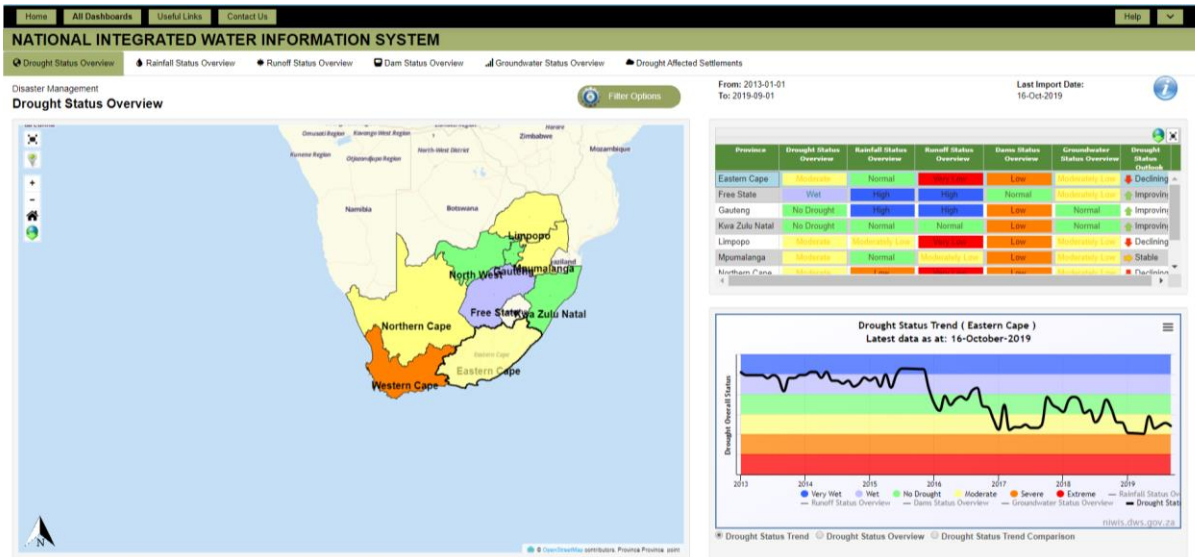


Figure 2-7 Drought status dashboard of the National Integrated Water Information System (NIWIS) hosted by the South African Department of Water and Sanitation (http://niwis.dws.gov.za/niwis2/)

Recognising the importance of the projected impacts of climate change on our water resources, the Department of Environmental Affairs (DEA) has highlighted the priority areas for implementation by various sectors. One of the priorities for the water sector is the use of ecosystem-based adaptation (EbA) through collaboration with Department of Rural Development and Land Reform (DRDLR) and Department of Agriculture, Forestry and Fishery (DEFF) for the Medium Term Strategic Framework (2019 MTSF) (Department of Environmental Affairs, 2017a). EbA is defined as the "use of biodiversity and ecosystem services (BES) as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change" (CBD – Convention of Biological Diversity, 2009). The DEA / DEFF proposed approach includes scaling up of the operations of Working for Water Programme, which has the mandate to improve the integrity of natural resources (https://www.environment.gov.za/projectsprogrammes/wfw; accessed 2 October, 2019).

2.3.1 Ecological infrastructure for drought mitigation under current and future climate

> In recent years, South Africa has experienced an El Niño-related drought reported to be one of the worst meteorological droughts since 1904. The average rainfall in this drought period (late 2014-2016) was about 403 mm compared to 608 mm over the last 112 years …
>
> South African Risk and Vulnerability Atlas, CSIR (2017: p. V)

The study areas in the current project primarily fall under the Grassland and Savanna biomes. A recent synthesis report on grasslands by Bengtsson et al. (2019) notes how grasslands have been undervalued in terms of ecosystem eservices they provide using case studies from South Africa and Northern Europe. Bengtsson et al. (2019) and Cadman et al.'s (2013) SANBI report on Grassland Ecosystem Guidelines notes that grasslands are effective in water capture, resulting in high infiltration and stream flow regulation through flood attenuation and releasing base flows during the dry season. Degradation of these areas (which is linked with unsustainable continuous grazing, conversion to commercial plantations or mining, expansion of dairy and subsistence farming, invasive aliens) reduces their influence on climate regulation and disaster risk reduction. The predictions of land cover change in an Eastern Cape catchment with communal farming suggests conversion of grasslands to woody plants and cultivated land by 2030 if the current trend of land cover change continues (Gibson et al., 2018). This also implies greater evapotranspiration and reduced water availability, which will impact on farmers.

Climate change is not only expected to impact water availability for humans, but also our freshwater ecosystems, according to the review by Dallas and Rivers-Moore (2014) on the consequences of climate change associated temperature and rainfall changes. These ecological consequences include impacts on water quantity (e.g. change in runoff patterns including duration and timing of flow; the frequency and intensity of extreme events), on water quality (e.g. increase in sedimentation, turbidity and salinisation), on the physical habitat (e.g. channel geomorphology change; reduced longitudinal and lateral connectivity), and in the biological dimension (e.g. change in communities, biodiversity, extinction of vulnerable species). The authors suggest promoting ecosystem resilience through various measures, including retaining environmental flows, re-establishing connectivity in rivers, and supporting catchment health for healthier freshwater ecosystems.

Natural vegetation facilitates infiltration and Turpie et al. (2017: see Figure 5d) estimated that the flow regulation services provided by natural vegetation is worth R52.3 billion annually; additionally, the authors noted that the highly vegetated areas in the east of South Africa are significant contributors to this monetary value. Similarly, for the uMngeni River catchment with over 6 million people, Jewitt et al. (2020) estimated that the benefits of clearing invasive aliens in the upstream catchment were significant (15.6 million m^3 water with savings of approximately R15 million per year in pumping costs).

An ecosystem service provided by healthy catchments is climate stabilisation (Postel and Thompson, 2005). Climate variability is natural and droughts have been part of the natural cycle in South Africa. However, future predictions are suggesting a hotter (Figure 2-8) and drier (Figure 2-9) South Africa, with longer duration of dry spells in many parts of the country (Figure 2-10). A South African case study in Eden District used an agrohydrological model to investigate the frequency of future natural disasters (floods, droughts, wildfires, storm waves) under various land cover and climate scenarios (Nel et al., 2014; Reyers et al., 2015). The study area naturally experiences floods followed by long periods of low rainfall (droughts), and the findings of the study were that climate change, along with other drivers (invasive species and land use change), will increase the frequency of natural disasters, especially floods and hydrological droughts. These natural disasters will impact the local economy, particularly the rural farmers who are particularly vulnerable to droughts, floods and wildfires. The studies concluded the need to mainstream ecosystem services into decision-making in order to reduce the risk of natural hazards. This is complemented by knowledge coproduction and partnerships with stakeholders so as to tackle the complex issues and implement actions.

The socio-economic implications of climate change and land degradation for rural livelihoods can be significant, and according to Sigwela et al. (2017) the members of the rural communities are acutely aware of the need for response strategies for managing their landscape. In contrast, Belle, Collins and Jordaan's (2018) evaluation of the health, management and understanding of wetlands for disaster risk reduction in Free State found that communal wetlands were in poor health and the locals didn’t see them as important for hazard reduction (for veld fires, droughts and floods), in comparison the wetlands in protected areas and on private commercial farms, suggesting the need for education, awareness and management plans. Notably, the Tsitsa Project was conceptualised with adaptation to climate change and resilience to climate related extremes using ecological infrastructure as a focus for research investment and natural resource management interventions like rehabilitation (Fabricius, Biggs and Powell, 2016). Additionally, the Green Village Project is a project in the Tsitsa River catchment investigating the value of ecological infrastructure for improving human well-being and reducing environmental risks for marginalised rural areas (Rowntree et al., 2019). The need for building resilient landscapes is essential in order for the social-ecological systems to “absorb, adapt and recover from disturbance” (O’Farrell et al., 2015: p. iii).

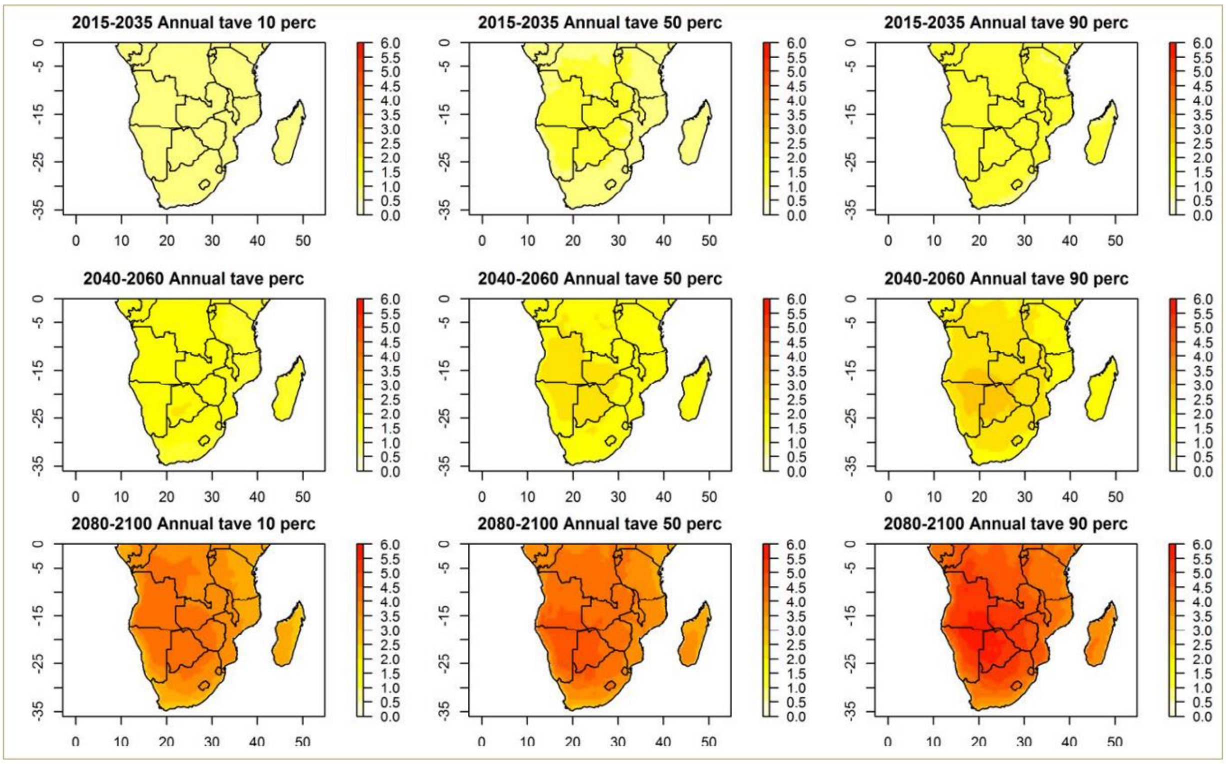


Figure 2-8 Projections of future change in average temperature over southern Africa (2015-2035, 2040-2060 and 2080-2100, relative to 1970-2000). The y-axis shows the temperature change (°C) per year based on the 10th percentile (left), median (middle), and 90th percentile (right) results for the IPCC Fourth Assessment Report (A2 emission scenario which assumes an unmitigated and unconstrained world; source: DST/CSIR, 2017).

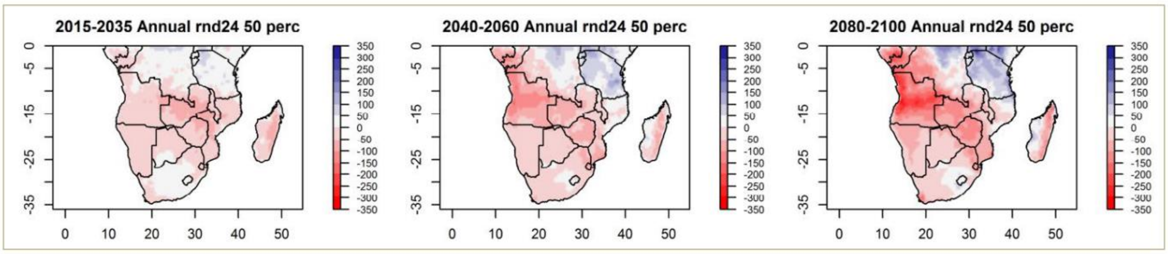


Figure 2-9 Projections of change in average annual rainfall (mm) (2015-2035, 2040-2060 and 2080-2100, relative to 1970-2000). The y-axis shows the change in rainfall (mm) per year based on the median of six downscaled models for the IPCC Fourth Assessment Report (A2 emission scenario which assumes an unmitigated and unconstrained world; source: DST/CSIR (2017).

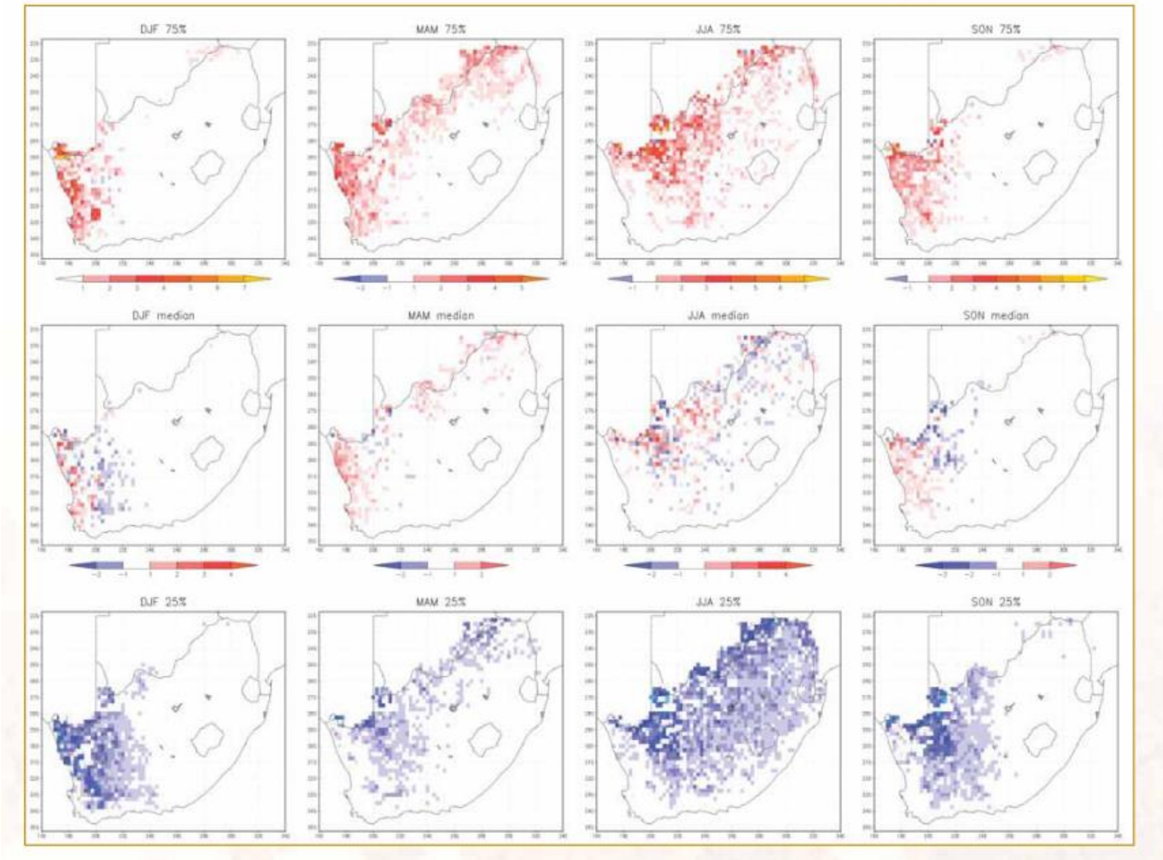
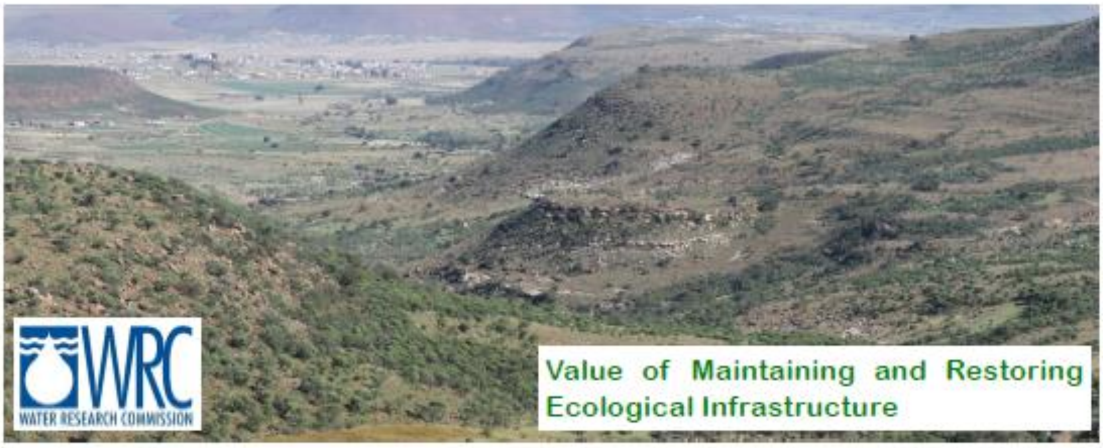


Figure 2-10 Projections of change in dry-spell duration (days) from Global Circulation Models (GCMs) under the A2 SRES scenario (2046-2065 relative to 1961-1990). Upper row: 75th percentile; Middle row: median, Bottom row: 25th percentile. Source: Department of Science & Technology (2012: p. 13)

2.4 Fact sheet on "Value of Maintaining and Restoring Ecological Infrastructure"

We hope the Fact Sheet generated by the project will be useful for society and government at various levels. It has been written to address the need for presenting the importance of ecological infrastructure in terms of water security. The value of maintaining and restoring EI can be used to support knowledge sharing of the importance of these infrastructures.

The following shows the Fact Sheet that was generated by the research team.



Value of Maintaining and Restoring Ecological Infrastructure

Some facts

Healthy land with rich biodiversity is more resilient to drought, as it is able to hold more water.

Over 40% of land across Earth is degraded (MEA, 2005) and the majority of people (83%) in sub-Saharan Africa depend on productive land and sufficient water for livelihoods (regreeningafrica.org).

Climate change adds to the pressures of degraded land with flooding, drought and rainfall variability. Sustainable land management is a climate mitigation strategy being promoted worldwide with particular attention to ecological infrastructure.

What is Ecological Infrastructure (EI)

Healthy and naturally-functioning ecosystems that provide ecosystem services are called Ecological Infrastructure. Maintaining and restoring EI is important for long-term sustainability, drought resilience and climate change mitigation. Examples of EI are: healthy grasslands, wetlands, rivers, riparian buffers (areas next to rivers), coastal dunes.

As climate change intensifies, nature's value is only increasing. It will play an essential role in helping human societies cope with the inevitable consequences of rising global temperatures. These include rising sea levels, more extreme rainfall, more frequent droughts and more frequent and intense storms – all impacts that NATO and the Pentagon recognize as significant threats to global security. Healthy natural systems can help reduce the damage caused by these changes (WWF 2018: p. 15)

ECOLOGICAL INFRASTRUCTURE PROVIDES ECOSYSTEM SERVICES

What are ecosystem services (ES)?

Ecosystem services encompass generation of flow of ecosystem outputs leading up to benefits derived by people from ecosystems.

Four types of ecosystem services with examples of benefits are:

a) Provisioning ES - food, fresh water, fiber, medicinal plants

b) Regulating ES - flood control, climate regulation, disease control

c) Cultural ES - places for recreation and spiritual experiences

d) Supporting ES - soil formation, nutrient cycling, habitat

Benefits from ecological infrastructure

Water quantity benefits

Higher baseflow (water in rivers during dry season)

Sustained water flows and higher assurance of supply

Healthier Landscapes

Reduced soil erosion and better retention of water by soil

Protection of biodiversity

Water quality benefits

Reduced amount of sediment in river water

Reduced amount of nutrients washed off land into river water

Mitigation of mining activities and toxic spills (chemical, oil)

Livelihood support and cultural benefits

Food and water security

Landscapes important for cultural and spiritual practices

Better quality river water

More productive and healthier grass for livestock grazing

Healthier wetlands provide resources for people (reeds, water)

Climate change adaption, mitigation and risk reduction

Reduced flood frequency and severity, and fire risk

Reduced impact of drought through higher assurance of supply

Reduced need for building dams (financial and ecosystem gains)

DEGRADATION AND INVESTMENT IN EI

What is land degradation?

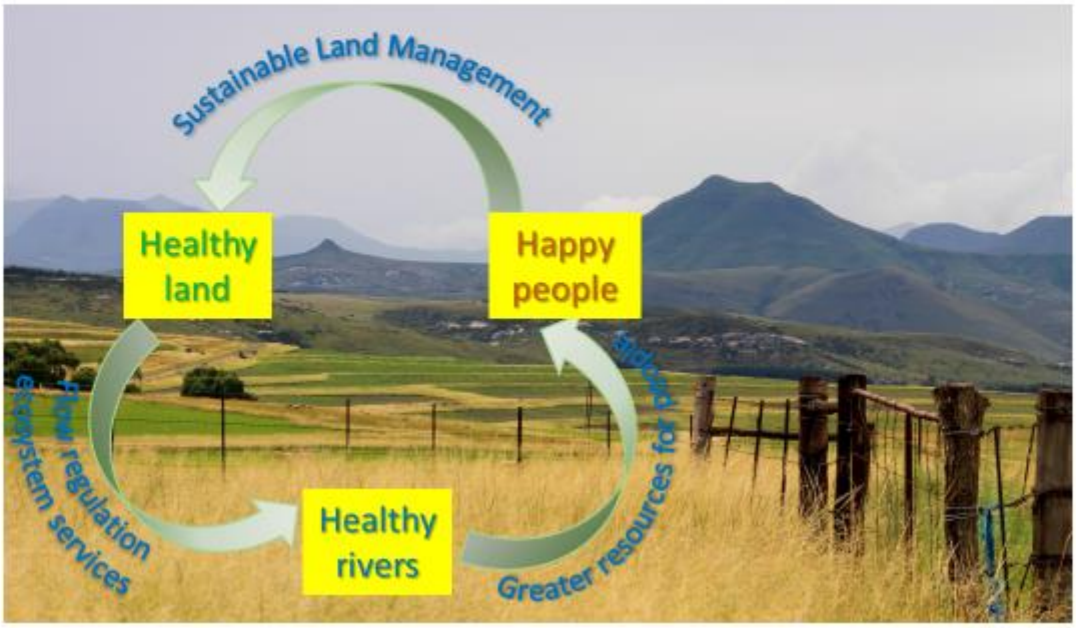
Land degradation decreases the ability of ecosystems to perform their ecological functions resulting in reduced ecosystem services or benefits for people. Therefore, maintenance and restoration of ecosystems is critical for long-term sustainability.

Linking science and policy for sustainability

Investment in EI is a strategy for accumulating various benefits to people including water and food security. This investment requires maintaining functioning EI and restoring degraded EI. The SANBI (2014) framework on investment in EI links to the South African National Development Plan 2030 actions 7 and 8, and Sustainable Development Goals 15 (Life on Land), 6 (Clean Water and Sanitation) and 13 (Climate Action). The benefits of this investment include hydroclimatic disaster risk reduction, environmental sustainability, resilience to extreme events like large fires, floods and droughts, assurance of water supply, and adaptation to climate change.

Nature-based solutions (NbS) or investment in ecological infrastructure

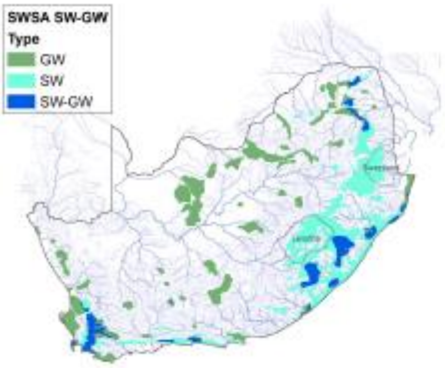
- Clearing of invasive alien plants, particularly near rivers and in mountain areas.
- Establishing, maintaining and restoring buffers around rivers
- Protecting and restoring wetlands
- Grazing management and restoring degraded grasslands
- Rehabilitating abandoned croplands

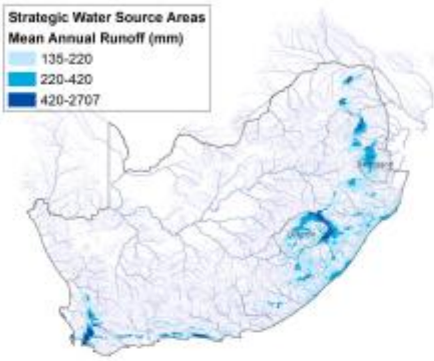


WHERE SHOULD WE INVEST IN EI?

Strategic Water Source Areas (SWSA)

South Africa has defined Strategic Water Source Areas (SWSAs; Figures below) for both surface water (22 SWSA-sw areas) and groundwater (37 SWSA-gw areas). These areas generate relatively large quantity of mean annual surface water runoff for their size and/or high groundwater recharge. Only 11% area of the SWSAs are in protected areas, so we need to manage and restore these SWSAs to promote sustainability and climate resilience. For example, the Working for Water programme has prioritised high mean annual runoff (MAR) SWSA-sw areas for invasive plants clearing.





Focusing our resources on key ecological infrastructure

Grasslands

Natural grasslands serve as browsing and grazing areas and they provide various ecosystem services related to livelihoods of indigenous communities.

River riparian areas

Riparian zones provide various ecosystem services including water filtration, flood protection, sediment regulation and habitat for organisms. They also provide various medicinal products, and therefore clearing invasive aliens from riparian zones is considered important for improving biodiversity.

Wetlands

Wetlands are a solution for greater water security as they play important roles in sediment, flow and flood regulation, and they can recharge groundwater aquifers. Rural communities also depend on these ecosystems for various resources, such as reeds and water.

WHAT IS THE STATUS OF LAND AND WATER RESOURCES?

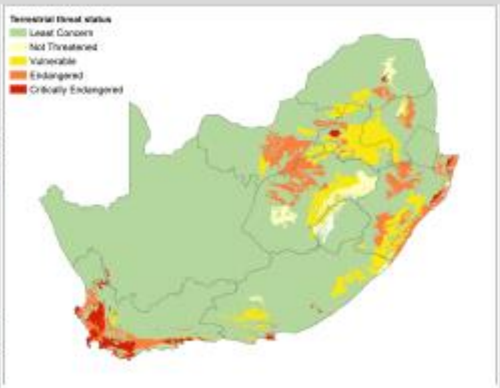
National Biodiversity Assessment (NBA)

The NBA 2018 is a milestone for South Africa in advancing our understanding of reporting status, monitoring and guiding actions towards protection and rehabilitation of the natural resources. Three main findings of NBA2018 are:

- Biodiversity in aquatic and selected terrestrial ecosystems is under pressure due to changes in hydrological regime and poor water quality. Overutilization of rangelands is leading to loss of cover and erosion.
- Habitat loss due to land clearing for croplands, plantations, human habitation and mining is a major pressure on terrestrial ecosystems.
- Woody invasive plants are affecting riverine areas, wetlands and mountain catchments.

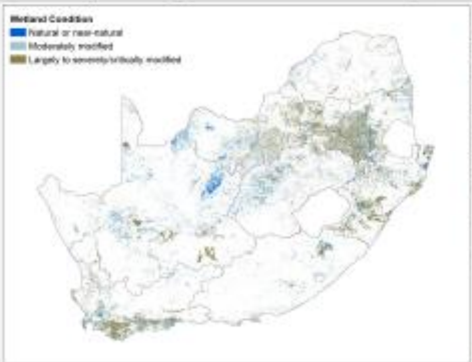
<u>Grasslands</u>

Excessive soil erosion and gully formation is a significant consequence of land degradation in grasslands and has been linked to human activities such as continuous grazing or overgrazing, frequent fires, abandoned cultivation lands, livestock tracks and roads.



<u>Rivers</u>

Riparian zones are important as they connect the river to the catchment. Rivers act as invasion pathways for invasive aliens, which utilise large quantities of water and thus, clearing these areas increases yield from rivers and dams.



<u>Wetlands</u>

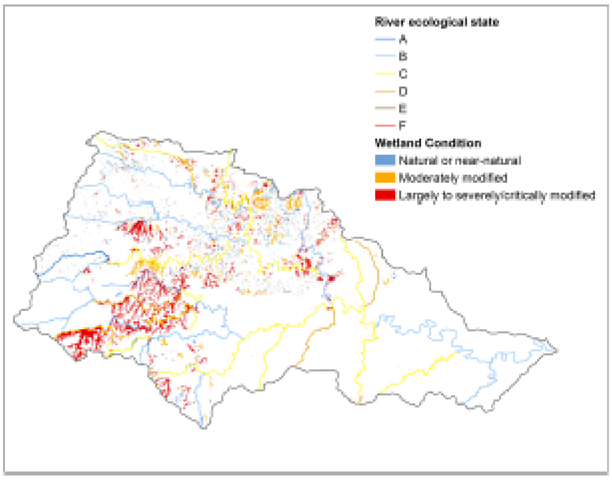
Loss of wetlands leads to increased landscape and sediment connectivity, increased flood frequency and severity, and reduced base flows. Wetlands are the most threatened of all South Africa's ecosystems (62% of wetland ecosystem types are Critically Endangered) and 67% are largely to severely ecologically modified.

*** The maps on this page are generated from NBA 2018 data.**

CASE STUDY OF BENEFITS OF REHABILITATING LAND

Tsitsa River Catchment in the Eastern Cape

The Tsitsa River catchment hosts SWSA (both surface and groundwater) in the Drakensberg. There are two large dams (Ntabelanga and Lalini) planned for the catchment. The rivers in Tsitsa catchment range in ecological condition from A (natural) to D (heavily modified), with most of the modified rivers located in the middle sections of the river (see map, data from NBA 2018). This affects the water quality as well as the riverine biodiversity.



The Tsitsa catchment hosts approximately 3,500 wetlands, majority of which are critically endangered and are not protected (see map, data from NBA 2018). Almost half of the wetlands are either critically modified or moderately modified. This is of concern as wetlands provide various benefits linked to water and food security, including nutrient and sediment trapping, purification of water, flood control, groundwater replenishment, and hosting of animal and plant biodiversity.

Sedimentation is an extensive problem in the catchment, not only due to loss of soil but also reduction in the lifespan of the dams. Therefore, the National Department of Environment Forestry and Fisheries is funding the Tsitsa Project to restore the landscape to reduce siltation and, at the same time, ensure sustainability of ecosystems that improve the livelihoods of the people who live there. Under this project, rehabilitation of ecological infrastructure has been put forward as a cost effective strategy compared to building man-made structures. There are various reports that provide the background and case for this rehabilitation including:

Huchzermeyer N., Sibiya S., Schlegel P. and Van der Waal B. 2018. Cultivated Land in the Upper Tsitsa River Catchment T35 A-E. Unpublished report to Department of Environmental Affairs.

Rowntree K., Conde-Aller L., Fox H. and Duma M. 2019. The Green Village Project. Volume 1: Improving socio-economic conditions through landscape greening, a case study from the Tsitsa River catchment, uMzimvubu basin. WRC report TT777/1/18. Pretoria, South Africa.

Schlegel P., Huchzermeyer N. and Van der Waal B. 2018. Wetlands in Catchment T35 A-E: Wetland type, current condition and rehabilitation prioritisation. Ecosystem report, Tsitsa Project, Rhodes University.

Sigwela, A. Elbakidze M., Powell M. and Angelstam P. 2017. Defining core areas of ecological infrastructure to secure rural livelihoods in South Africa. Ecosystem Services 27(January): 272–280.

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MEA 2005. Ecosystems and Human Well-Being—Synthesis of the Millennium Ecosystem Assessment, Island Press. DOI: 10.1196/annals.1439.003.

South African National Planning Commission 2012. National Development Plan 2030: Our future - make it work. [online] pp.1–479. Available at: <http://www.dac.gov.za/sites/default/files/NDP 2030 - Our future - make it work_0.pdf>.

South African National Biodiversity Institute (SANBI) 2014. A Framework for Investing in Ecological Infrastructure in South Africa. Lead contributors Tracey Cumming, Amanda Driver, Mark Botha, Jeffery Manuel, John Dini, Anthea Stephens. Pretoria, South Africa.

WWF 2018. Living Planet Report 2018. Aiming higher. Grooten M. and Almond R.E.A. (eds). Gland, Switzerland.

WRC reports

WRC Report No. 2267/1/15: Towards Building Resilient Landscapes by Understanding and Linking Social Networks and Social Capital to Ecological Infrastructure.

WRC Report No. TT754/1/18: Identification, Delineation and Importance of the Strategic Water Source Areas of South Africa, Lesotho and Swaziland for the Surface Water and Groundwater.

WRC Report No. TT815/20: Enhancing Water Security Through Restoration and Maintenance of Ecological Infrastructure: Lessons from the Umngeni River Catchment, South Africa

The Water Wheel articles (http://www.wrc.org.za/the-water-wheel/)

July/Aug 2013: Investing in ecological infrastructure for our future water security.

July/Aug 2014: Mpumalanga wetland rehab partnership a win for ecological infrastructure.

May/Jun 2016: Research into ecological infrastructure steps up a gear.

Sept/Oct 2020: Investing in freshwater ecological infrastructure for a resilient tourism economy: A call for action.

More information

IUCN. Nature-based Solutions (https://www.iucn.org/theme/nature-based-solutions).

South African National Biodiversity Institute. Ecological Infrastructure (https://www.sanbi.org/biodiversity/science-into-policy-action/mainstreaming-biodiversity/ecological-infrastructure/)

Water Research Commission (WRC) Knowledge Hub (wrc.org.za).

Factsheet compiled by Sukhmani Mantel, Sinetemba Xoxo, Bawinile Mahlaba, Jane Tanner & David le Maitre under WRC project K5/2928/1

CHAPTER 3 ECOLOGICAL INFRASTRUCTURE EXTENT, CURRENT STATE AND PRIORITISATION (AIM 2)

Photos taken by: GEF5 Research Team, Machubeni (2017-2020). BS Xoxo (2019)

This chapter addresses Aim 2 of the project: *Assessment of ecological infrastructure extent, current state and prioritisation in three focal catchments*.

The aim of prioritisation is to evaluate where we get the best returns in terms of improved EI and benefits to society. The research results provided in this chapter is the foundation step which identifies those areas and prioritises them. For implementation, this evaluation requires that government programs such as Working for Water, Working for Wetlands, Working for Ecosystems, etc. decide how much rehabilitation can be conducted in the priority areas and over what time frame (which depends on available financial resources). However, it is important to remember that water gains are permanent and long-term, and so costing specific rehabilitation work is highly site and method specific. Although we have not conducted a financial evaluation, there are other studies which can be replicated in these study catchments, such as Jewitt et al. (2020).

3.1 Global trends in land degradation and role of big data

South Africa's scarce freshwater resources, together with increasing water quality issues, have raised the profile of water resources and highlighted the many deficiencies in water governance and management. We have recognised since the 1800s that changes in ecosystems can result in non-linear changes in ecosystems and impact on the ecosystem goods and services that are essential to us (Millennium Ecosystem Assessment (MA), 2005a; Blignaut and Aronson, 2008; Egerton, 2017). This flow is dependent on renewable natural capital, which comprises functioning ecosystems and native biodiversity. Various studies have investigated the links between land-use / land degradation and its hydrological impacts (e.g. Global: Scanlon et al., 2007; South Africa: Le Maitre et al., 2007; USA: Schilling et al., 2008; China: Lin et al., 2015; East Africa: Guzha et al., 2018). These links have also been examined from an ecosystem services perspective (e.g. review: Brauman et al., 2007; South East Asia: Tomich, Thomas and Van Noordwijk, 2004; South Africa: Rebelo et al., 2019). The following sections provide a summary of land degradation trends determined by global assessments, and the role of big data in sustainable management of natural resources. This sets the context for the evaluation on land degradation that we have conducted under this project.

3.1.1 Global assessments of trends in land degradation and ecosystem services

Two recent reports by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) are worth reviewing to understand the global context of ecological infrastructure and land degradation. The IPBES (2019) global assessment report on biodiversity and ecosystem services aimed to generate comprehensive and systematic global assessments by experts from across the world for evidence-based policy decisions. Their report highlights four key messages (IPBES, 2019: p. 9-19) that are summarised here:

A. Nature and its vital contributions to people, which together embody biodiversity and ecosystem functions and services, are deteriorating worldwide.

B. Direct and indirect drivers of change have accelerated during the past 50 years.

C. Goals for conserving and sustainably using nature and achieving sustainability cannot be met by current trajectories, and goals for 2030 and beyond may only be achieved through transformative changes across economic, social, political and technological factors.

D. Nature can be conserved, restored and used sustainably while other global societal goals are simultaneously met through urgent and concerted efforts fostering transformative change.

The status and trends towards SDG 6, 13 and 15 in IPBES (2019) indicates that the targets are at best being supported partially (Figure 3-1). Overall, the report noted that none of the 44 assessed targets (under SDG 1, 2, 3, 6, 11, 13, 14, 15) scored as having good/positive status and trends and thus that possibility does not appear in Figure 3-1.

Selected Sustainable Development Goals	Selected targets (abbreviated)	Recent status and trends in aspects of nature and nature's contributions to people that support progress towards target *: Poor/Declining support	Recent status and trends in aspects of nature and nature's contributions to people that support progress towards target *: Partial support	Uncertain relationship
6 Clean water and sanitation	6.3 Improve water quality	■		
	6.4 Increase water use and ensure sustainable withdrawals	■		
	6.5 Implement integrated water resource management		■	
	6.6 Protect and restore water-related ecosystems	■		
13 Climate action	13.1 Strengthen resilience to climate-related hazards	■		
	13.2 Integrate climate change into policies, strategies and planning		■	
	13.3 Improve education and capacity on mitigation and adaptation	Unknown		
	13a Mobilize US$100 billion/year for mitigation by developing countries	Unknown		
	13b Raise capacity for climate change planning and management	Unknown		
15 Life on land	15.1 Ensure conservation of terrestrial and freshwater ecosystems	■		
	15.2 Sustainably manage and restore degraded forests and halt deforestation	■		
	15.3 Combat desertification and restore degraded land	■		
	15.4 Conserve mountain ecosystems		■	
	15.5 Reduce degradation of natural habitats and prevent extinctions	■		
	15.6 Promote fair sharing of benefits from use of genetic resources		■	
	15.7 End poaching and trafficking	■		
	15.8 Prevent introduction and reduce impact of invasive alien species	■		
	15.9 Integrate biodiversity values into planning and poverty reduction		■	
	15a Increase financial resources to conserve and sustainably use biodiversity		■	
	15b Mobilize resources for sustainable forest management		■	

Figure 3-1 Progress towards achieving selected targets of SDGs relevant to current project that were assessed by IPBES (2019) (modified from Figure SPM 7, page 36)

The second IPBES report of note reviewed the status, trends and extent of direct drivers of land degradation (Figure 3-2; IPBES, 2018a) in terms of the impacts on global biodiversity and ecosystem services. These impacts are presented for managed systems relative to well-managed production systems (instead of initial state for the system) in order to provide insights into where appropriate management is needed. The managed system types included grazing lands, croplands and agroforestry, and native forests and tree plantations. The introduction of invasive species in Southern Africa is noted to have resulted in a decrease (10-20%) in the biodiversity and ecosystem services with >50% of land affected; non-timber natural resource extraction has impacted a similar extent of land. The recent trends in resulting land degradation for Southern Africa are either stable or increased during the assessment period (2005-2015). One of the conclusions of the report is that “rapid expansion and unsustainable management of croplands and grazing lands is the most extensive global direct driver of land degradation” (IPBES 2018a: p. 14). The corresponding Regional Assessment Report on Biodiversity and Ecosystem Services for Africa (IPBES, 2018b: p. 16) indicates that the drivers of biodiversity change (which include climate change, habitat conversion, overharvesting, pollution, invasive alien species, illegal wildlife trade and demographic change [as an indirect driver]) are increasing for terrestrial and inland waters in Southern Africa (Figure 3-3).

3.1.2 Role of big data in sustainable management of natural resources

To manage natural resources well, data on the ground are essential. The paucity of environmental ground data in Africa, and many developing countries, is a major constraint for sustainable management of natural resources. Various models, such as rainfall-runoff models for water resources, have been developed over the years as frameworks to identify and understand catchment-river links and the processes involved, in order to facilitate meaningful and effective decisions. However, models can be limited in the useful information they provide if the data for calibrating and validating them are sparse or unavailable.

From a water resources modelling perspective, the historical reduction in the number of observation networks (both rainfall and streamflow) on the ground in South Africa is a major concern (Pitman, 2011), as it increases the uncertainty associated with the inputs and the processes in decision making models. Satellite imagery has stepped into this role over the past few decades (Hughes, 2007; Gibson et al., 2009; Politi, Rowan and Cutler, 2016), with more and more remote sensing platforms expanding the availability of free data since the launch of Landsat's first mission in the early 1970s. The advantages of remote sensing data are enormous in terms of spatial and temporal extents, which far surpass most ground monitoring programs. Currently, various products for South Africa have utilised Landsat imagery, e.g. the South African National Land Cover 2013/14 (Department of Environmental Affairs, 2015a) and the more recently released SANLC 2018 (Department of Environmental Affairs, 2018). There is, similarly, huge potential for other satellite datasets for managing our catchments and water resources (e.g. Politi, Rowan and Cutler, 2016; Gwate et al., 2018; Gibson et al., 2018) and for achieving SDGs (see Figure 3-4). In recent years, the use of big data through platforms such as Google Earth Engine is on the rise due to the ease of access and computation through cloud resources to a wide range of interested stakeholders, both within and outside the academic field (e.g. Gorelick et al., 2017; Dong et al., 2019; Münch, Gibson and Palmer, 2019).

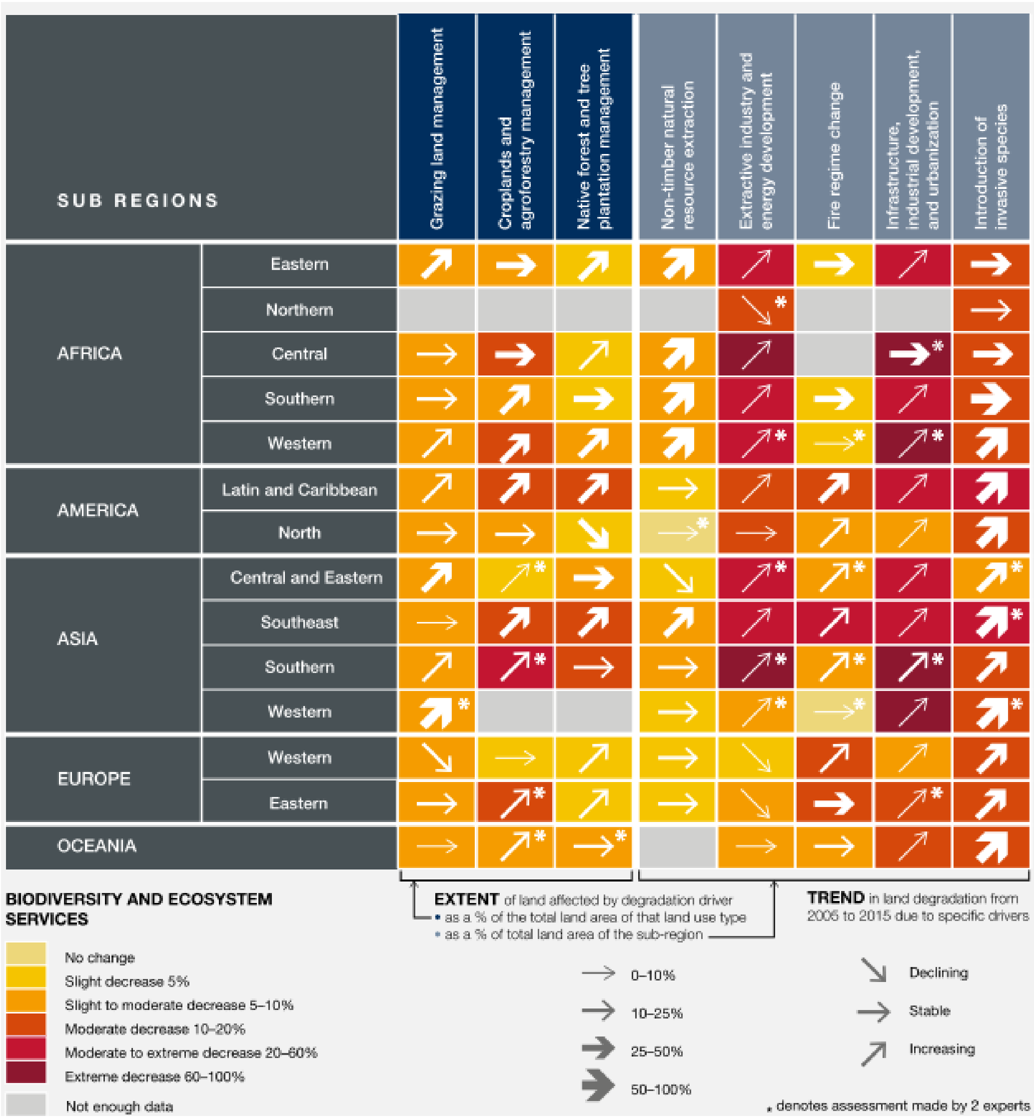


Figure 3-2 The status, trends (recent period 2005-2015) and extent (as % of land areas) of direct drivers of land degradation globally (Source: Figure SPM.5 of IPBES, 2018a: p. 21). The report was generated from regional expert opinions and information from ≥ 3 experts was used for each block in the figure with the exception of some blocks where * denotes that only two experts contributed to the evaluation and grey cells where a minimum of two experts were not available

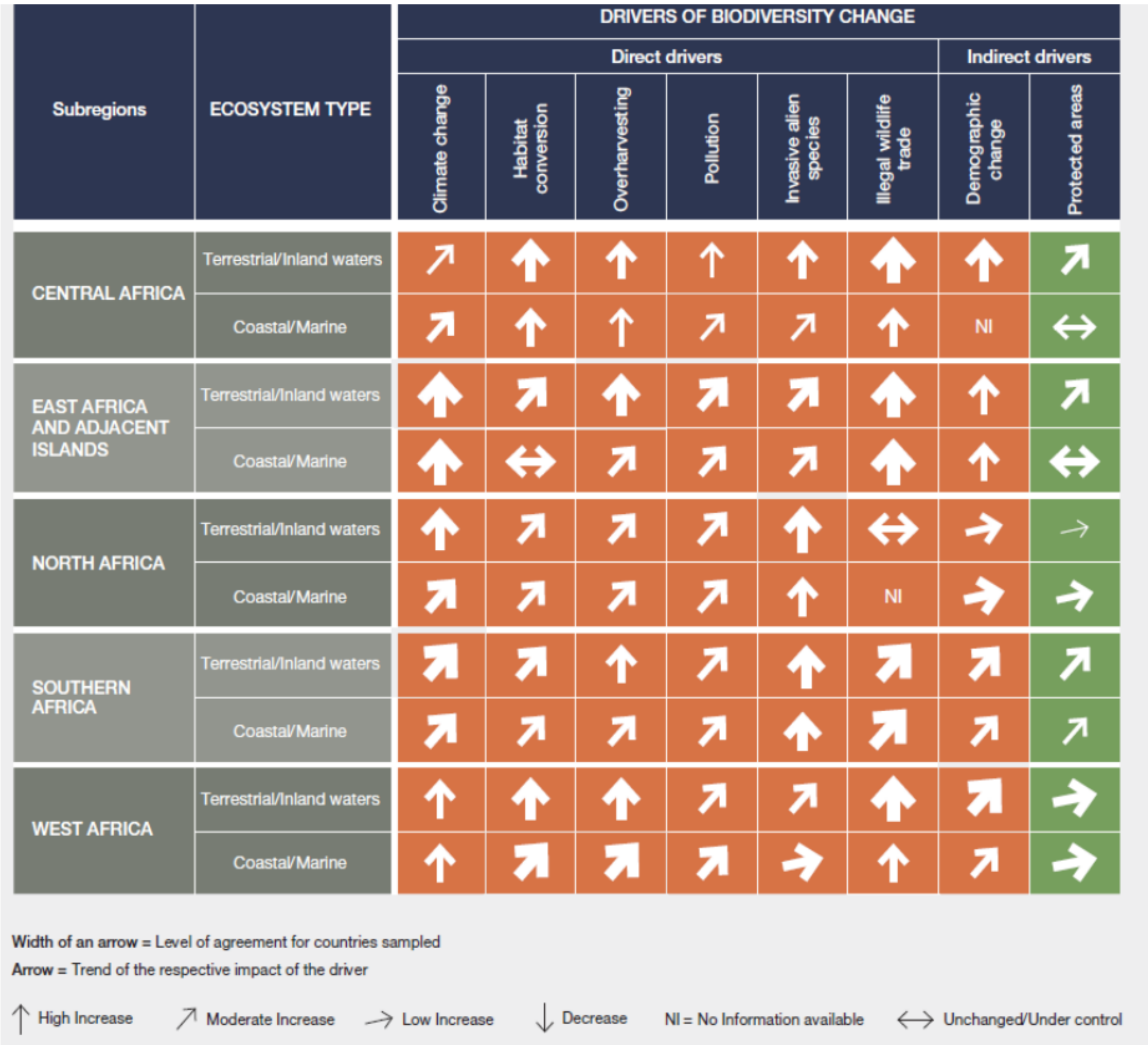


Figure 3-3 Qualitative assessment of drivers of biodiversity change for terrestrial and inland waters are on the increase (mostly moderate and high levels) across Africa (Source: Table SPM.1 of IPBES 2018b: p.16). For southern Africa, the report notes moderate increase in impact from climate change, habitat conversion, pollution and illegal wildlife trade; and high increase in impact from overharvesting and invasive alien species

In the context of the present study, land degradation assessment approaches are vital to guide and support land degradation interventions (e.g. Easdale et al., 2019; Gonzalez-Roglich et al., 2019). In South Africa, land degradation has been previously assessed at a national scale based on the status of agricultural land with the help of expert opinions by 453 agricultural experts (Hoffman and Todd, 2000) and later, using satellite data (Bai and Dent, 2007). This satellite-based net primary productivity (NPP) degradation assessment used Rain Use Efficiency (RUE) and Residual Trend Analysis adjusted Normalised Difference Vegetation Index (NDVI) at 1 km spatial resolution as proxies to measure degradation (Wessels et al., 2007; Bai and Dent, 2007). The assessment of land degradation by Bai and Dent (2007) linked the loss of ecosystem services to the human population and communal areas for the years 1981-2003 (see Figure 3-5). A total of 29% of the degraded areas were noted to be croplands (equivalent to 41% of all cultivated areas), 37% were rangelands and 33% forests (Bai and Dent, 2007: p. i). These numbers are comparable, but slightly higher than those derived for a global assessment by Bai et al. (2008: p. i) which found that across the world, degrading land consisted of >20% croplands and 20-25% rangelands (the remaining 42% was broadleaved and needle leaved forests). von Maltitz et al. (2019) however suggest the need to combine the results of recent remote sensing products with ground level perceptions of land degradation, which are based on longer-term history and experience of the landscape.

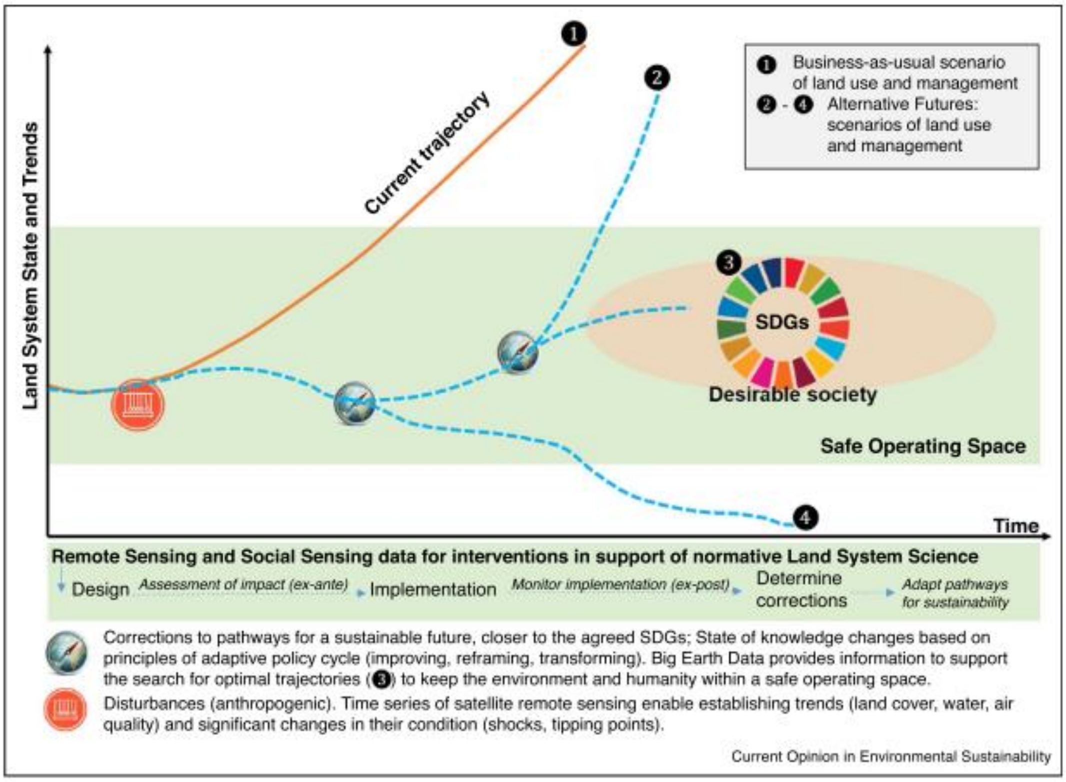
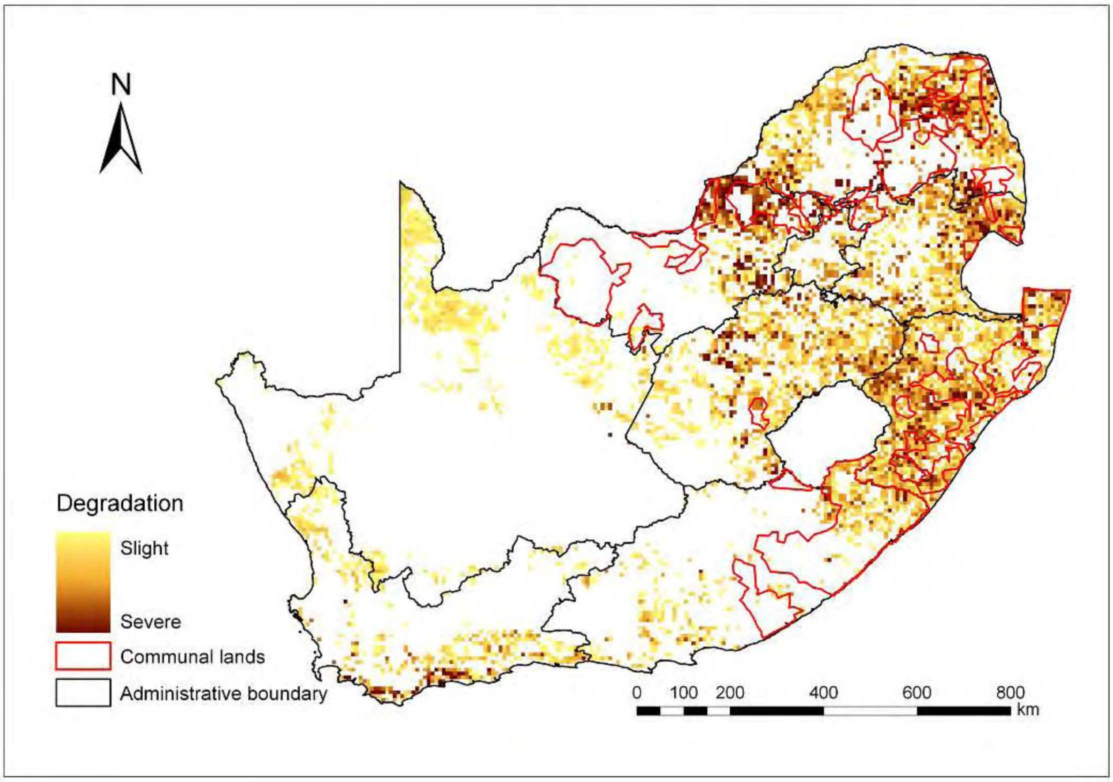


Figure 3-4 Figure from Dong et al. (2019) showing the role of remote sensing data as an intervention for land management



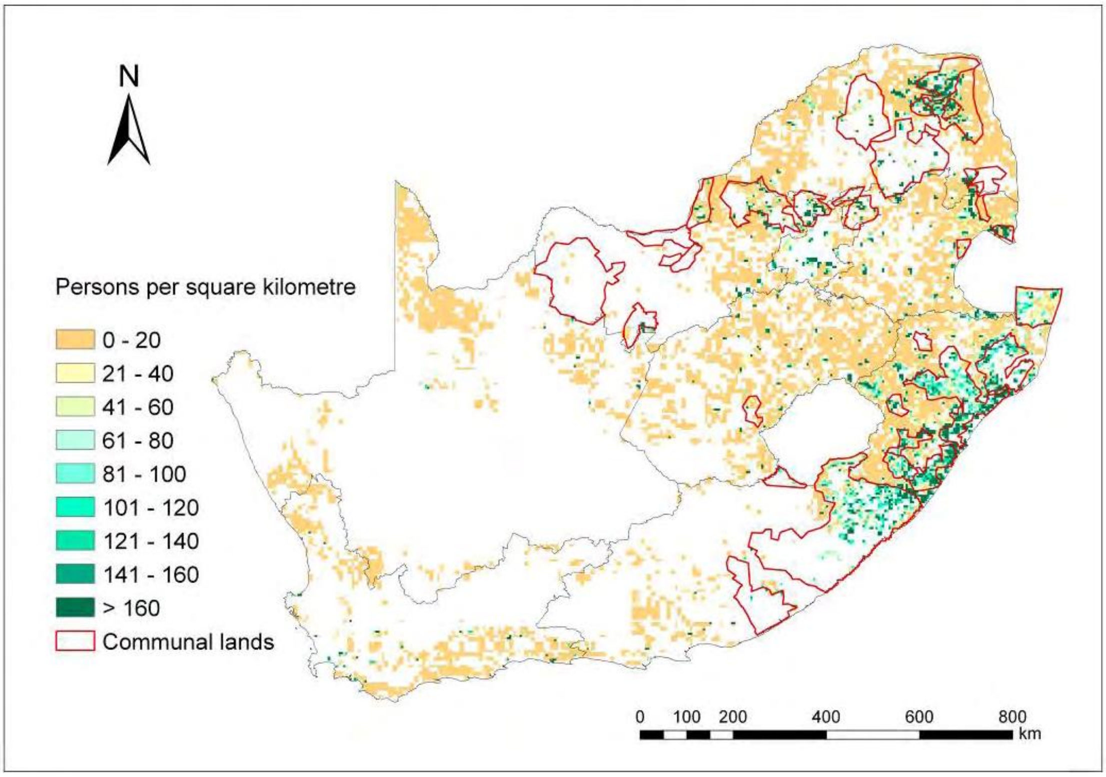


Figure 3-5 (a) Land degradation from 1981 to 2003 (annual NDVI which is RUE rainfall-adjusted) in relation to communal lands and (b) the population and communal areas affected by land degradation. Source: Bai and Dent (2007: Figures 12 and 16).

3.2 Spatial EI maps for three focal catchments and their condition

The following sub-sections present the relevant spatial maps of the focal catchments that can be classified under one of two categories: (i) spatial data related to land degradation, (ii) spatial data on ecological infrastructure derived from recent national evaluations that inform the rehabilitation prioritisation (presented in Section 3.3). Collating the spatial maps of EI in the focal catchment is important for identifying their location, and for management and rehabilitation prioritisation process. The spatial databases that have been interrogated include:

a. Degraded natural vegetation from NLC 2009 (presented in Section 1.3)

b. Strategic Water Source Areas (presented in Section 1.3)

c. National Invasive Alien Plant Survey (NIAPS) dataset 2010

d. National Biodiversity Assessment (NBA) 2018

3.2.1 National Biodiversity Assessment 2018

The National Biodiversity Assessment (NBA) 2018 is a milestone for South Africa in advancing our understanding towards reporting status, monitoring and guiding actions towards protection and rehabilitation of the natural resources (Figure 3-6). One of the key outputs from NBA 2018 are the new indicators, such as species protection level, Red List index and rates of terrestrial habitat loss (Skowno et al., 2019a). A second innovation is a seamless map connecting the terrestrial, marine and estuarine ecosystems, as well as detailed maps of ecosystem types in various realms. The sections below present the relevant datasets for the focal catchments.

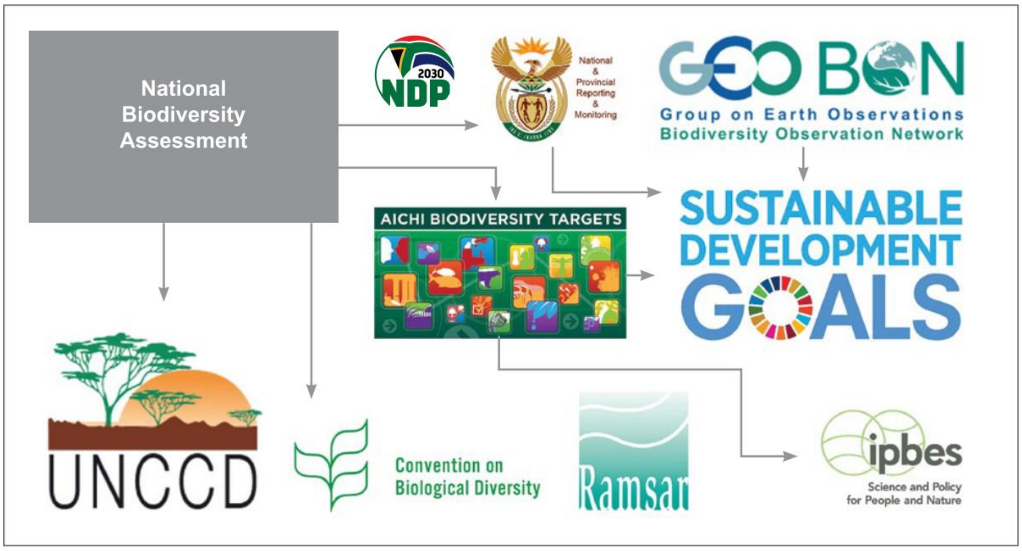


Figure 3-6 The NBA provides input towards various commitments by SA government. Source: Skowno et al. (2019a: Figure 17)

The NBA 2018 notes various pressures across the realms, four of which are highlighted below for their relevance to the current project’s work (Skowno et al., 2019a: p. 48-50):

a. The major pressures on biodiversity in aquatic (inland aquatic, estuarine, coastal) and selected terrestrial ecosystems are changes in hydrological regime and poor water quality

b. The main pressure in terrestrial realms is habitat loss due to clearing of land for croplands, plantations, human habitation and mining

c. Terrestrial and inland aquatic ecosystems are being impacted by overutilization of rangelands, which results in loss of cover and erosion

d. Biological invasions are impacting all realms, with woody invasive plants affecting riverine areas, wetlands and mountain catchments.

The NBA 2018 utilised the ecological condition for various realms to evaluate the reduction in ecosystem function, which is associated with an increase in ecosystem restoration costs (Table 2 and Figures 26-27 in Skowno et al., 2019a). The threat status for the ecosystems has been defined along a spectrum of levels: Critically Endangered (CR), Endangered (EN), Vulnerable (VU) and Least Concern (LC). According to Figure 3-7, rivers and wetlands are of significant concern with threatened status (CR, EN and VU categories), in terms of both ecosystem types and ecosystem extent.

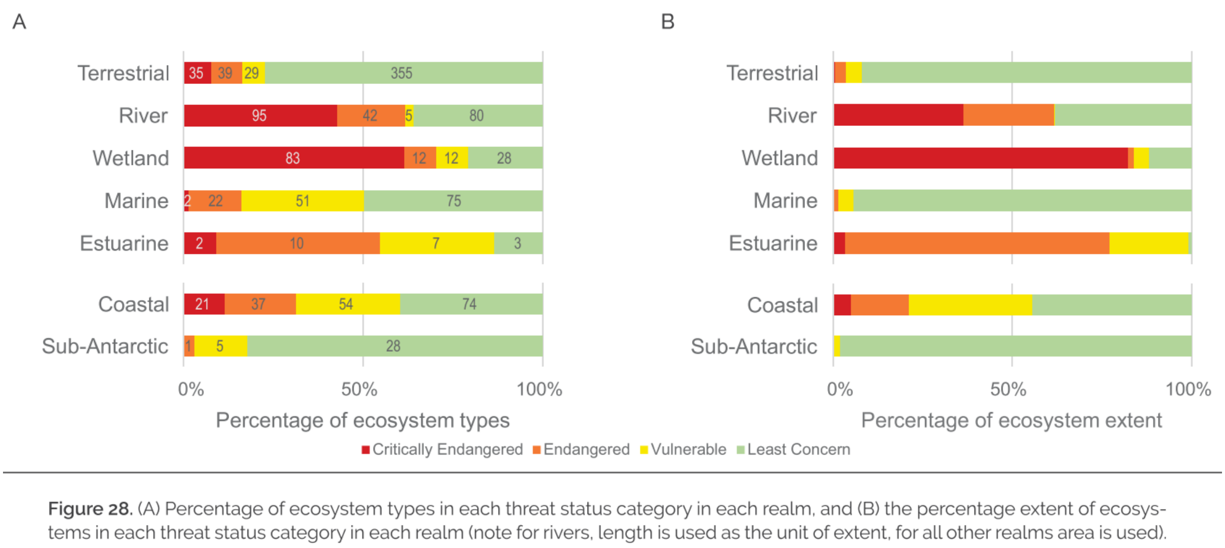


Figure 3-7 Threat status by (A) ecosystem types and (B) ecosystem extent in each realm covered in NBA 2018. The extent for rivers used river length as the unit. Source: Skowno et al. (2019a: Figure 28)

3.2.2 NBA 2018 Terrestrial realm status for focal catchments

Figure 3-7 appears to suggest that the terrestrial realm is not as threatened as other realms; however, considering the extent of the terrestrial area and the fact that rehabilitating these areas contributes to rehabilitating aquatic areas, healthy terrestrial realm is important. Secondly, the high level of endemism and the wide diversity and number of terrestrial ecosystem types (458) highlights the importance of this realm. Humans also receive various ecosystem services from the terrestrial system that has been outlined in the background sections above. Skowno et al. (2019b: p. 11) note that there are 103 threatened (35 CR, 39 EN and 29 VU) terrestrial ecosystems, and the two key pressures are habitat loss and overutilization of rangelands. The sections below provide the NBA 2018 Terrestrial realm evaluation for the three case study catchments.

3.2.2.1 NBA 2018 Terrestrial: White Kei catchment

The White Kei catchment has no threatened terrestrial ecosystems (Figure 3-8) and the protection level is primarily none to poor protection across the catchment (Figure 3-9).

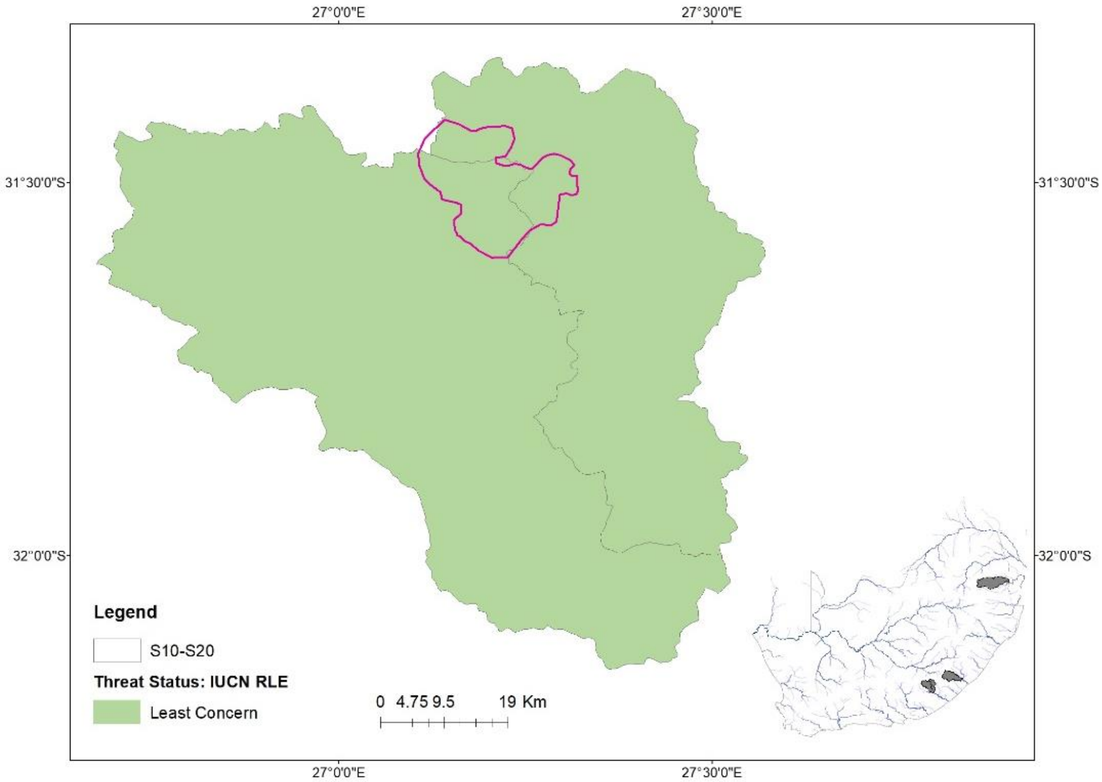


Figure 3-8 Threat status of terrestrial realm (NBA 2018) in White Kei using the IUCN Red List of Ecosystems (RLE)

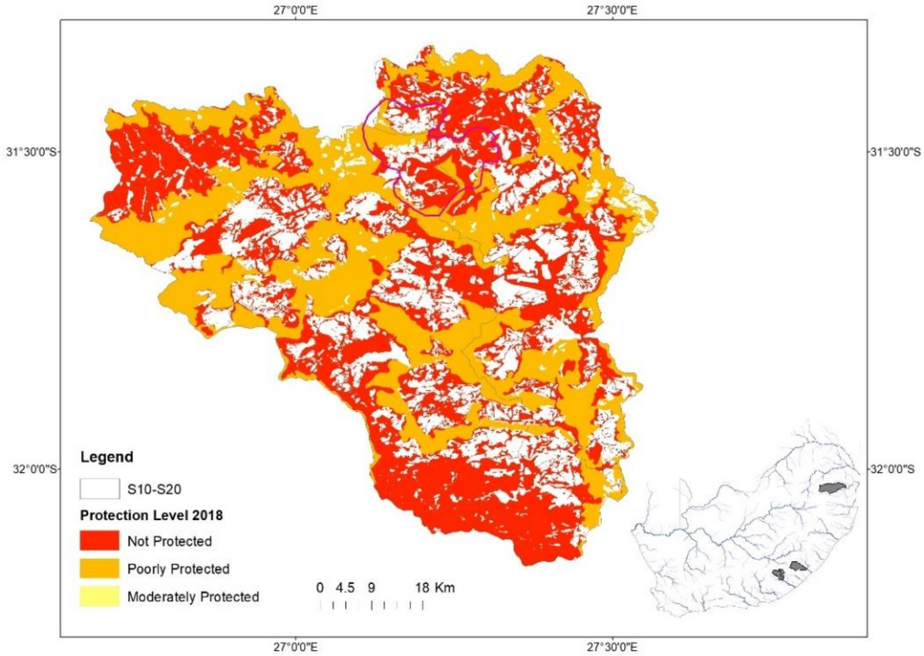


Figure 3-9 Protection level (NBA 2018) for the terrestrial realm in White Kei catchment

3.2.2.2 NBA 2018 Terrestrial: Tsitsa River catchment

The threat status of the terrestrial ecosystems in the Tsitsa River catchment is primarily of least concern with the exception of the lower catchment with an ecosystem type that is vulnerable (Figure 3-10). The upper catchment is poorly protected and the lower catchment with vulnerable terrestrial ecosystems is not protected (Figure 3-11).

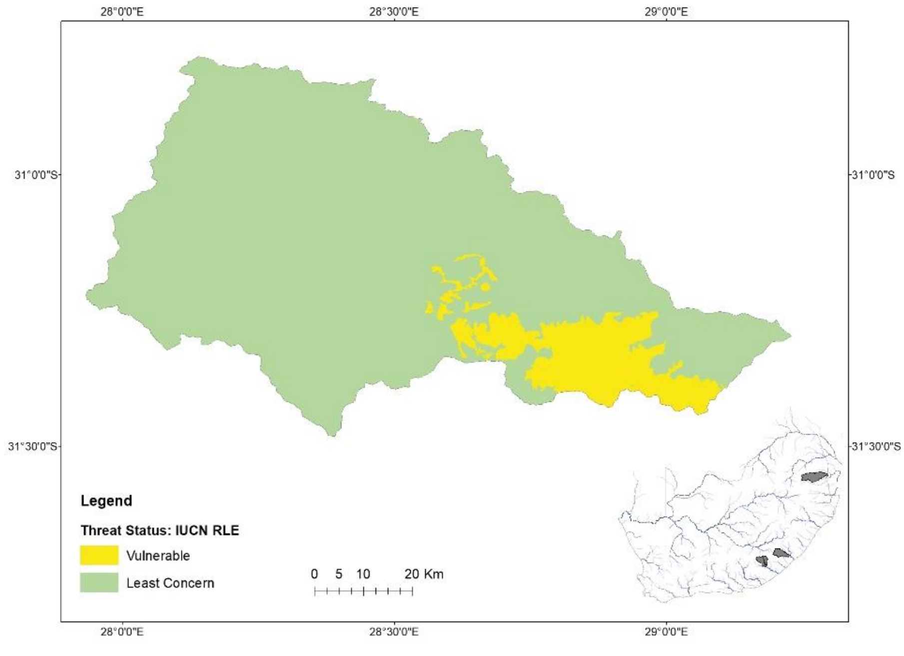


Figure 3-10 Threat status of terrestrial realm (NBA 2018) in Tsitsa catchment using the IUCN Red List of Ecosystems (RLE)

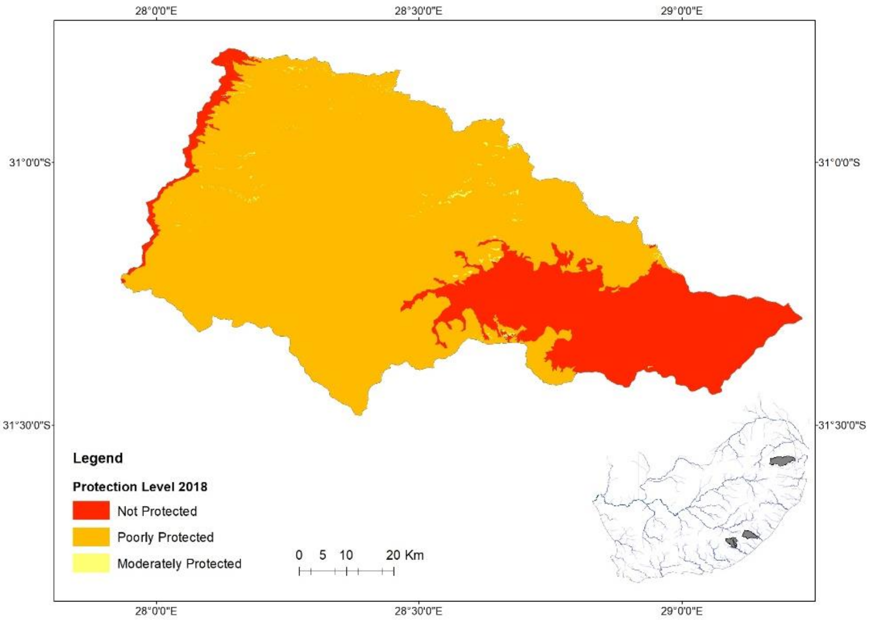


Figure 3-11 Protection level (NBA 2018) for the terrestrial realm in Tsitsa catchment

3.2.2.3 NBA 2018 Terrestrial: Crocodile River catchment

The terrestrial realm in Crocodile catchment is classified as endangered in the middle sections (Figure 3-12). The project focal area of X21 has some vulnerable and endangered ecosystem types in the lower catchment area and a majority of this area is poorly protected (Figure 3-13).

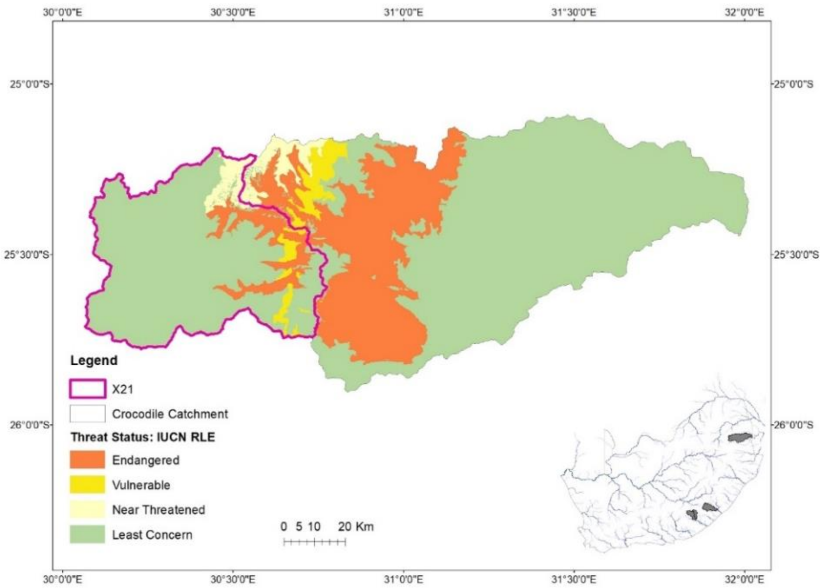


Figure 3-12 Threat status of terrestrial realm (NBA 2018) in Crocodile catchment using the IUCN Red List of Ecosystems (RLE)

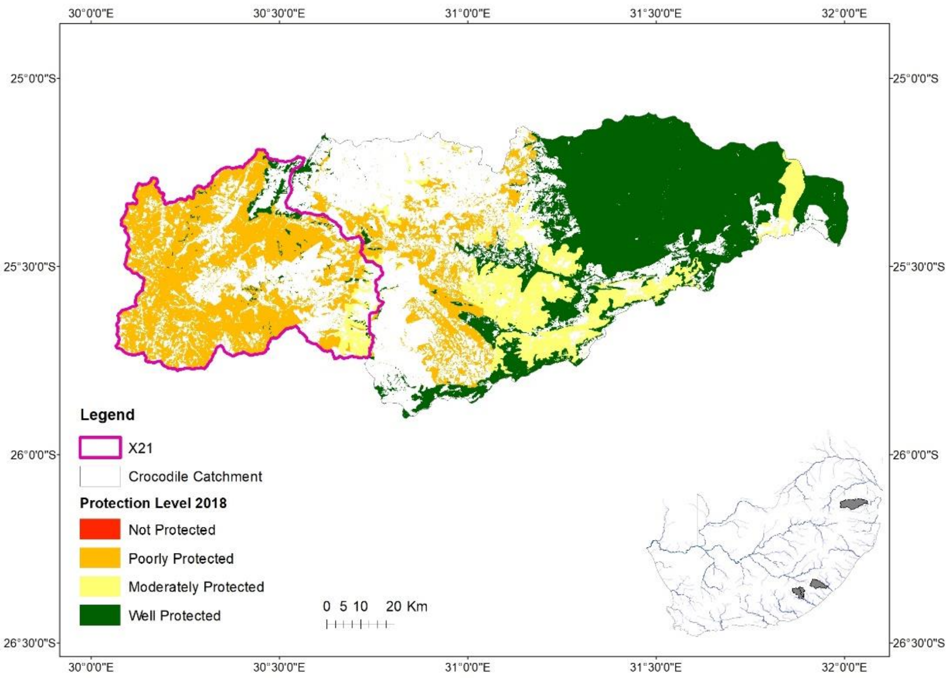


Figure 3-13 Protection level (NBA 2018) for the terrestrial realm in Crocodile catchment

3.2.3 NBA 2018 River status and SWSA

South Africa hosts a large number of rivers, many of them shared with the neighbouring countries (Figure 3-14). Over 60% of South African river ecosystems are threatened (95 CR, 42 ER, 5 VU out of a total of 222 types; see Figure 3-7A) and over 60% of the riverine ecosystem extent is also critically endangered or endangered (Figure 3-7B). Skowno et al. (2019a) notes that only one-third of the river ecosystems (by their total length) are in natural or near-natural ecological condition and that tributaries are generally less impacted than the mainstem rivers (Figure 3-15); notably, the evaluation is a desktop assessment of low confidence.

The relevant maps for the focal catchments are provided in the sections below including maps indicating the river condition, Ecosystem Threat Status (ETS) of the rivers, as well as the location of flagship and free-flowing rivers. The ETS is considered a key indicator of intactness of an ecosystem, and is also a function of loss of vital aspects of the ecosystem's structure, function and composition (Skowno et al., 2019b: p. 17); the NBA2018 categorises the ETS into Critically Endangered (CR), Endangered (EN), Vulnerable (VU) or Least Concern (LC) categories. The WWF-World Wide Fund for Nature (2006: p. 2) defines a free-flowing river as one 'that flows undisturbed from its source to its mouth, at either the confluence with a larger river, an inland sea or at the coast'. South Africa has defined 19 flagship free-flowing rivers that are considered to be top priority because of the importance of their biodiversity and ecosystem processes (Nel et al., 2011b). Maps of these for the focal catchments are provided below.

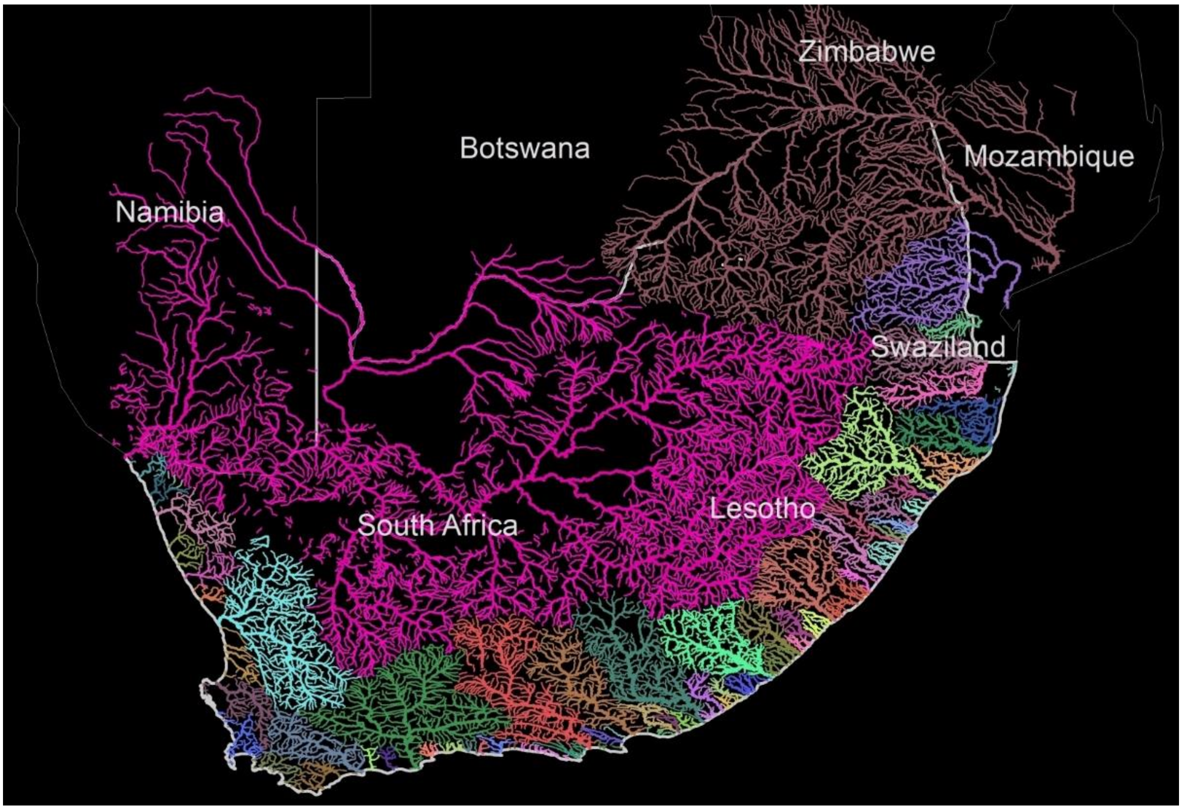


Figure 3-14 The diversity of rivers of South Africa shared with its neighbouring countries, each river system is indicated by a different colour

The NBA 2018 also includes an updated Freshwater Ecosystem Priority Areas (FEPA) 2018 dataset (originally defined by Nel et al., 2011a) that includes 22 Strategic Water Source Areas for surface water (SWSA-sw) and 37 Strategic Water Source Areas for groundwater (SWSA-gw) that are considered to be important for water and economic security (Skowno et al., 2019b; Le Maitre et al., 2018a).

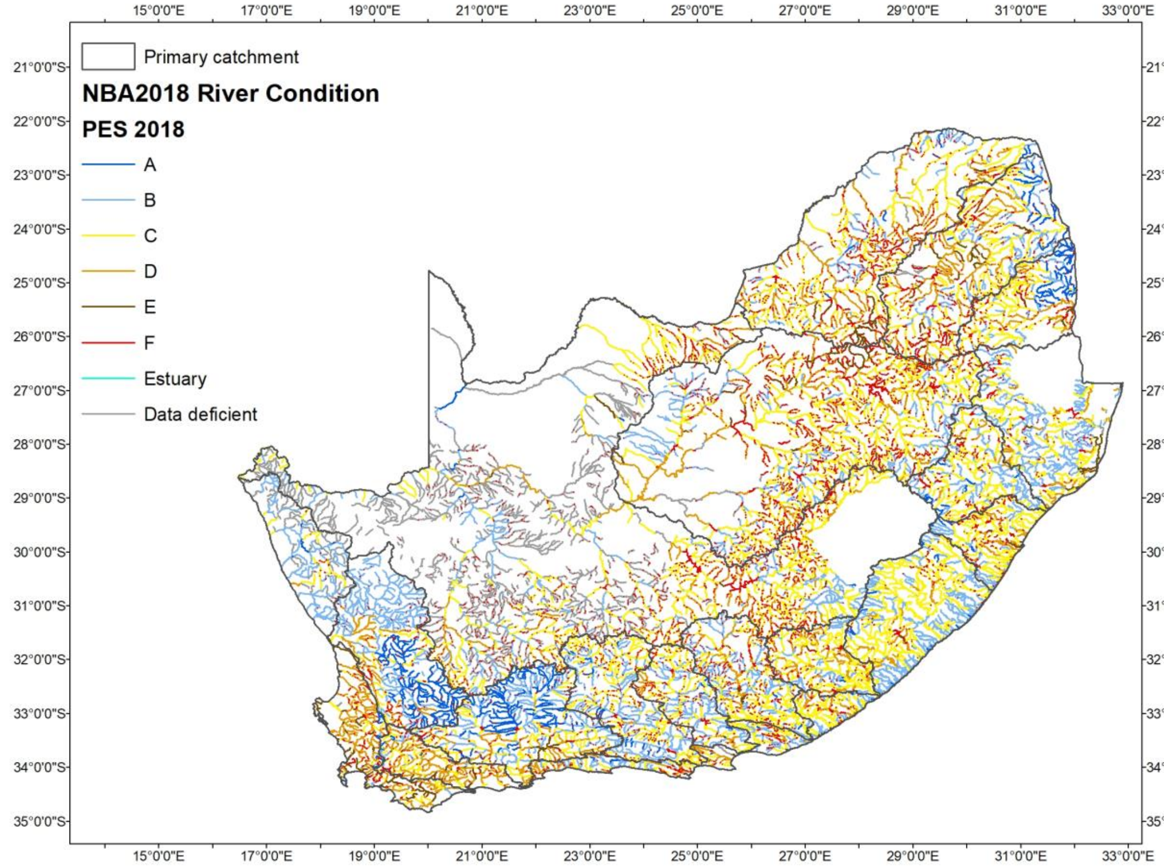


Figure 3-15 River condition of South African rivers using a desktop assessment in NBA 2018 (van Deventer et al., 2019b)

3.2.3.1 NBA 2018 Rivers: White Kei catchment

The rivers in the White Kei catchment are in near-natural (B; some tributaries) to critically modified (F) condition (Figure 3-16). The ETS for a majority of the White Kei Rivers is either endangered or critically endangered (Figure 3-17) but there are no flagship or free-flowing rivers (Nel et al., 2011b) and a small section of the catchment contributes as a surface water SWSA (Figure 3-18).

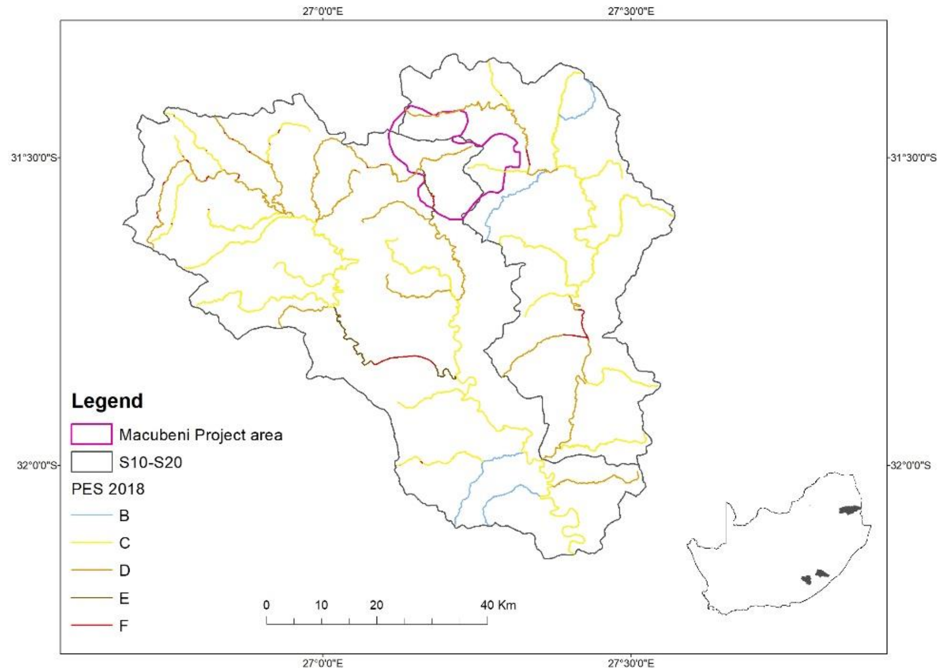


Figure 3-16 River condition of White Kei River and tributaries defined by NBA 2018 (van Deventer et al., 2019b)

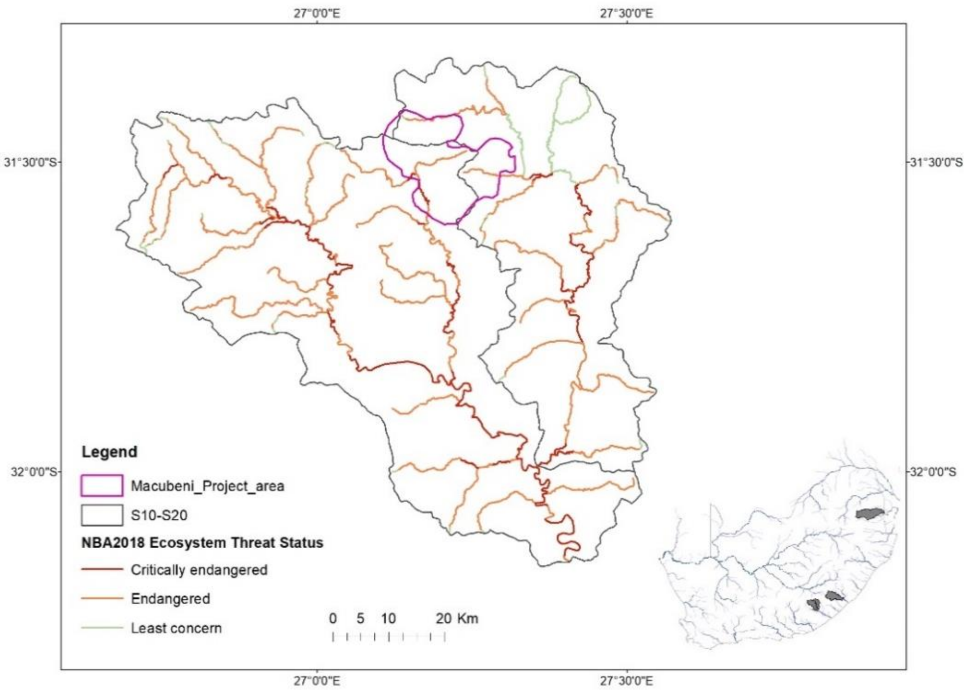


Figure 3-17 Ecosystem Threat Status (ETS) of White Kei River and tributaries defined by NBA 2018 (van Deventer et al., 2019b)

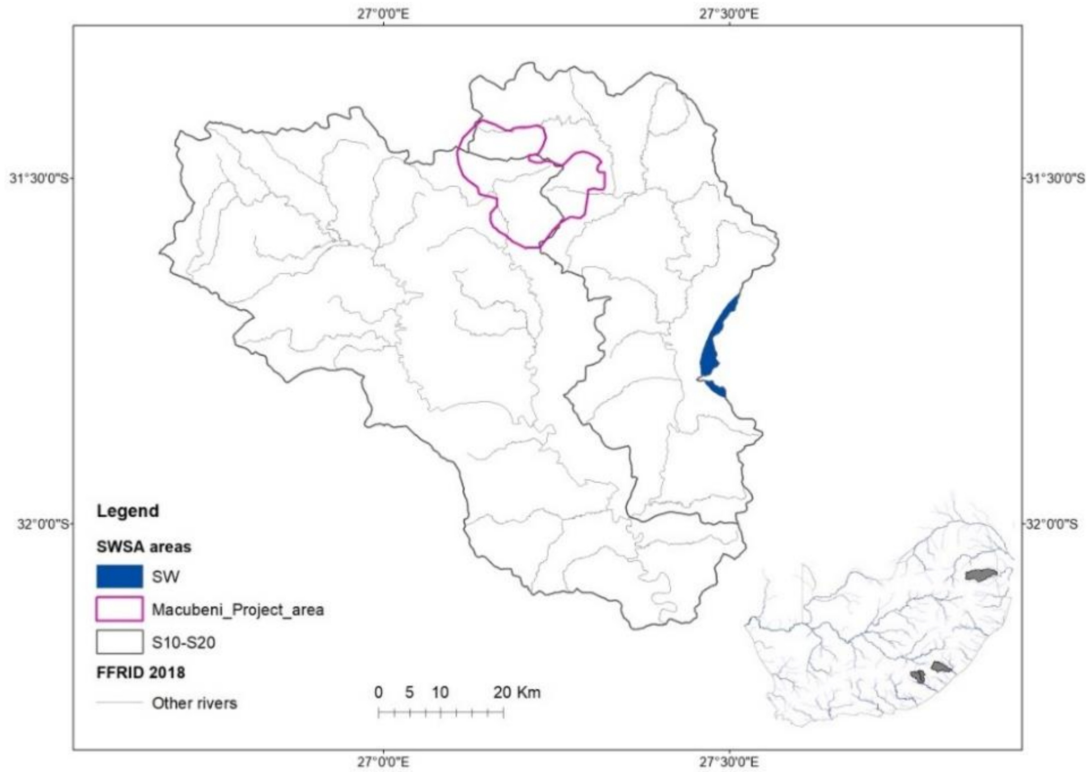


Figure 3-18 Flagship and free-flowing rivers derived from NBA 2018 (Nel et al., 2011a; Van Deventer et al., 2019b) overlaid on SWSA (Le Maitre et al., 2018a) for the White Kei catchment

3.2.3.2 Case study 2: Tsitsa River catchment

The rivers in Tsitsa catchment have a range of ecological conditions from A (natural) to D (heavily modified) with two small sections of the river classified as F (critically modified) (Figure 3-19). A majority of the upstream and lower rivers have a natural state. The rivers have an ETS of either endangered or critically endangered (Figure 3-20). Although there are no flagship or free-flowing rivers, a significant part of the catchment is classified as important SWSA areas for surface water, groundwater or both (Figure 3-21).

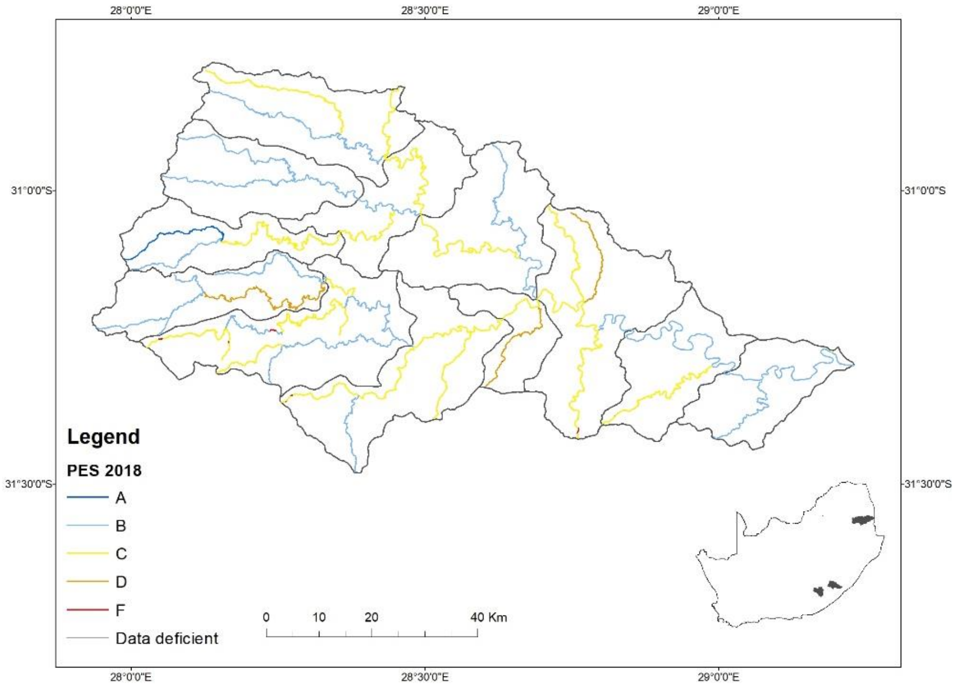


Figure 3-19 River condition of Tsitsa River and tributaries defined by NBA 2018 (van Deventer et al., 2019b)

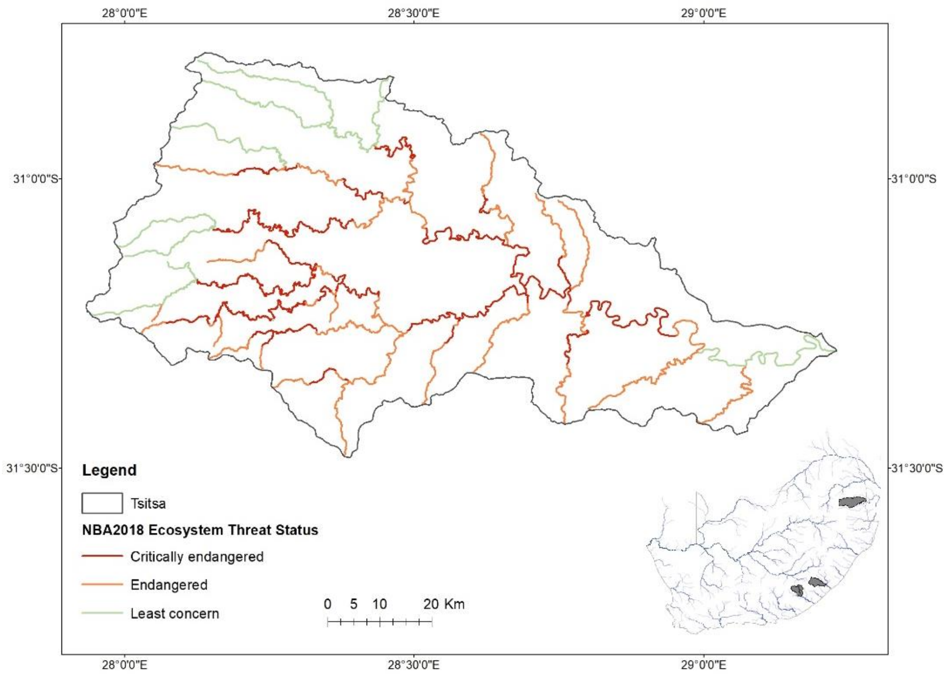


Figure 3-20 Ecosystem Threat Status (ETS) of Tsitsa River and tributaries defined by NBA 2018 (van Deventer et al., 2019b)

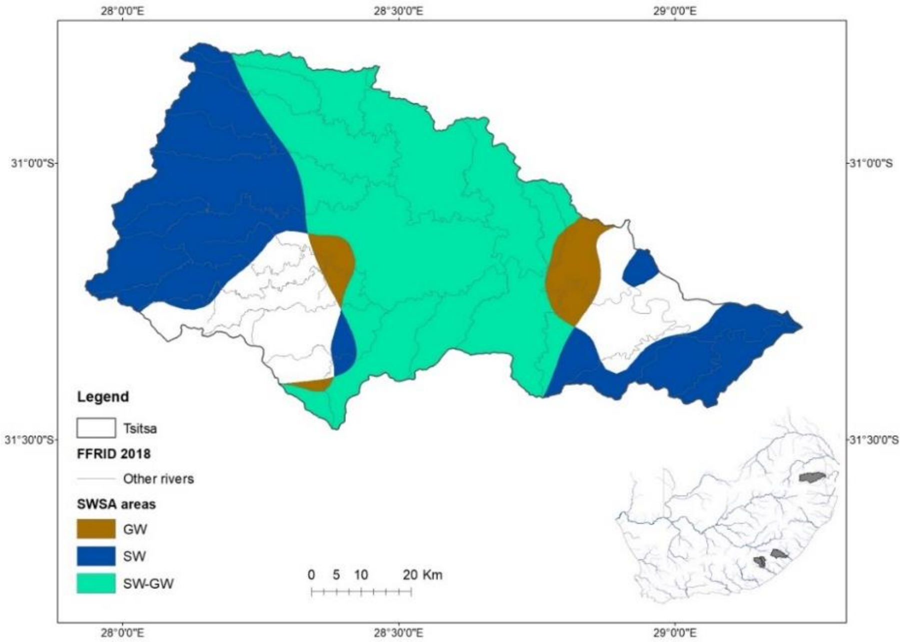


Figure 3-21 Flagship and free-flowing rivers derived from NBA 2018 (Nel et al., 2011a; Van Deventer et al., 2019b) overlaid on SWSA (Le Maitre et al., 2018a) for the Tsitsa River catchment

3.2.3.3 Case study 3: Crocodile River catchment

The upstream rivers in the Crocodile catchment (particularly in X21) have been designated to be in condition C (moderately modified) with two tributaries in condition A (natural) (Figure 3-22). The X21 rivers are classified as either endangered or critically endangered (Figure 3-23). There are two free-flowing tributary rivers in the Crocodile catchment and the tributary located in X21 is also a flagship river (Figure 3-24). A significant proportion of the X21 catchment is considered an important surface water SWSA.

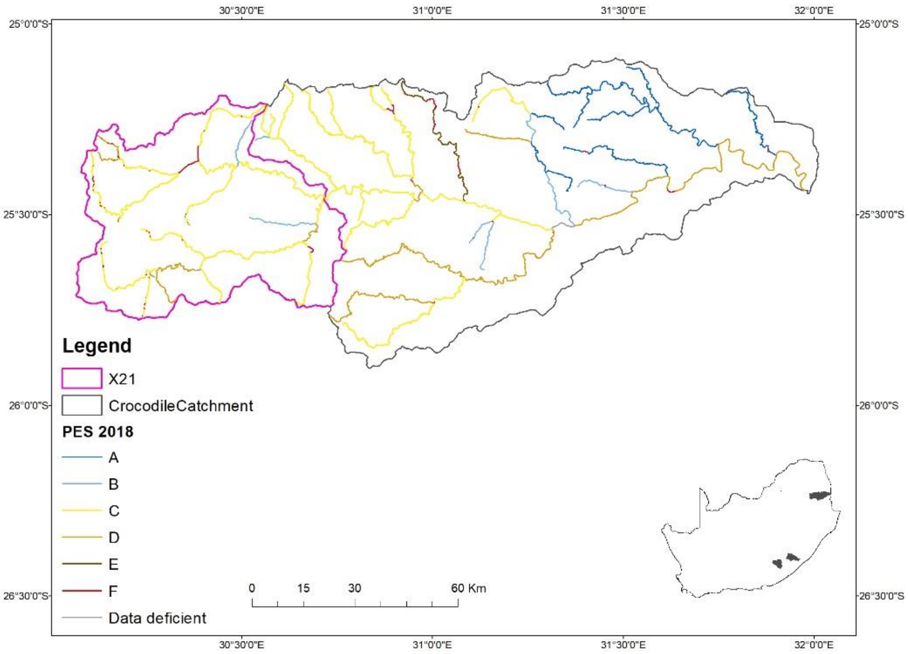


Figure 3-22 River condition of the Crocodile River and tributaries defined by NBA 2018 (van Deventer et al., 2019b)

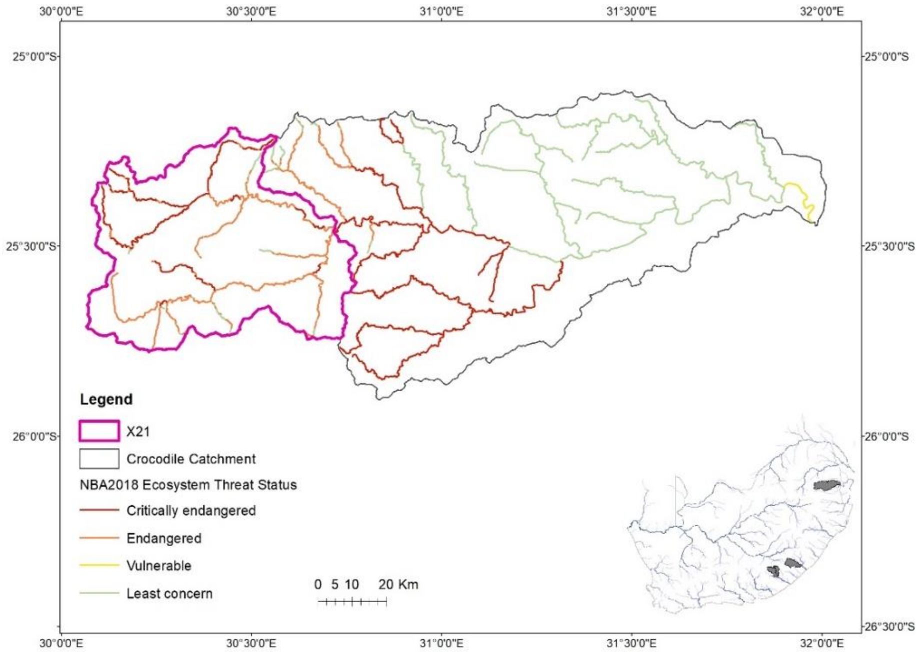


Figure 3-23 Ecosystem Threat Status (ETS) of Crocodile River and tributaries defined by NBA 2018 (van Deventer et al., 2019b)

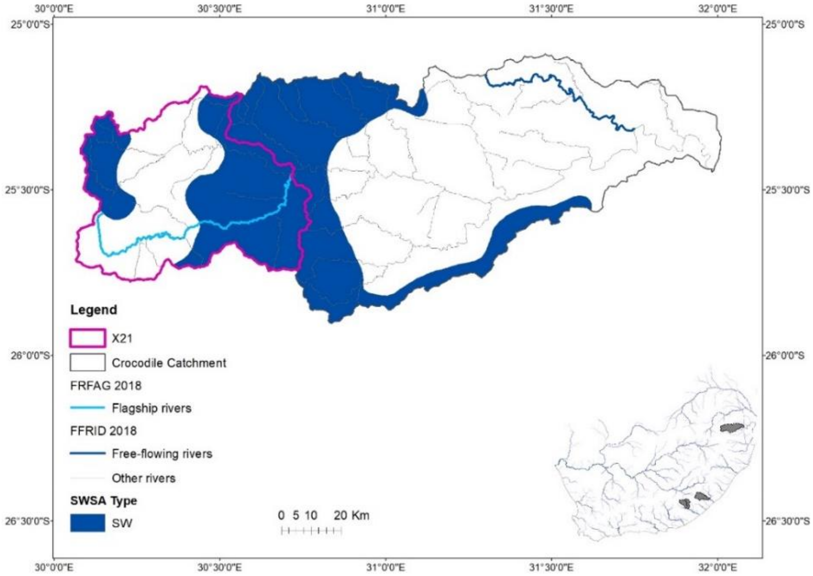


Figure 3-24 Flagship and free-flowing rivers derived from NBA 2018 (Nel et al., 2011a; Van Deventer et al., 2019b) overlaid on SWSA (Le Maitre et al., 2018a) for the Crocodile River catchment

3.2.4 National Wetland Map version 5 (NWM5)

According to NBA 2018 (Skowno et al., 2019a: p. 90), the status of South African wetlands is not good and their condition has declined in the past decade: "*Approximately 75% of inland wetland ecosystem types are both threatened and under-protected....Compared to the NBA 2011, where wetlands were found to be poorly mapped, highly threatened and Poorly Protected, the trends in ecological condition and protection level appear to be declining further*."

The following sub-sections present the maps derived from NWM5 (included in NBA 2018) for Ecosystem Threat Status (ETS), Ecosystem Protection Level (EPL) and the ecological condition for the wetlands in the focal catchments. ETS has been defined above in Section 3.2.4. EPL is an indicator of an ecosystem being adequately protected or not, and is categorised into four categories: Not Protected, Poorly Protected, Moderately Protected or Well Protected. The wetland condition is presented as three categories: Natural or near-natural (PES categories A/B), Moderately modified (PES category C) and Heavily to severely/critically modified (PES categories D/E/F) (van Deventer et al., 2019b: p. 162-163).

The map in Figure 3-25 shows the confidence ratings for the extent of inland wetlands (van Deventer et al., 2019a: p. 76) at sub-quaternary catchment level for the east of South Africa. Notably, the wetland extent in Machubeni is of low (1) confidence, which means that '*desktop mapping of the extent of inland wetlands was conducted by non-wetland specialists for a part of, or the full extent of the sub-quaternary catchment'*. In the Crocodile catchment, the wetlands extent confidence is low to medium (2), i.e. '*desktop mapping of the extent of inland wetlands was done by interns trained by wetland specialists for the full extent of the sub-quaternary catchment'*. In comparison, the wetland extent for the upper catchment of Tsitsa is of medium (3) confidence, i.e. '*desktop mapping of the extent of inland wetlands and HGM typing was done by wetland specialists for the full extent of the sub-quaternary catchment*', while the wetland extent in lower Tsitsa is of low (1) confidence.

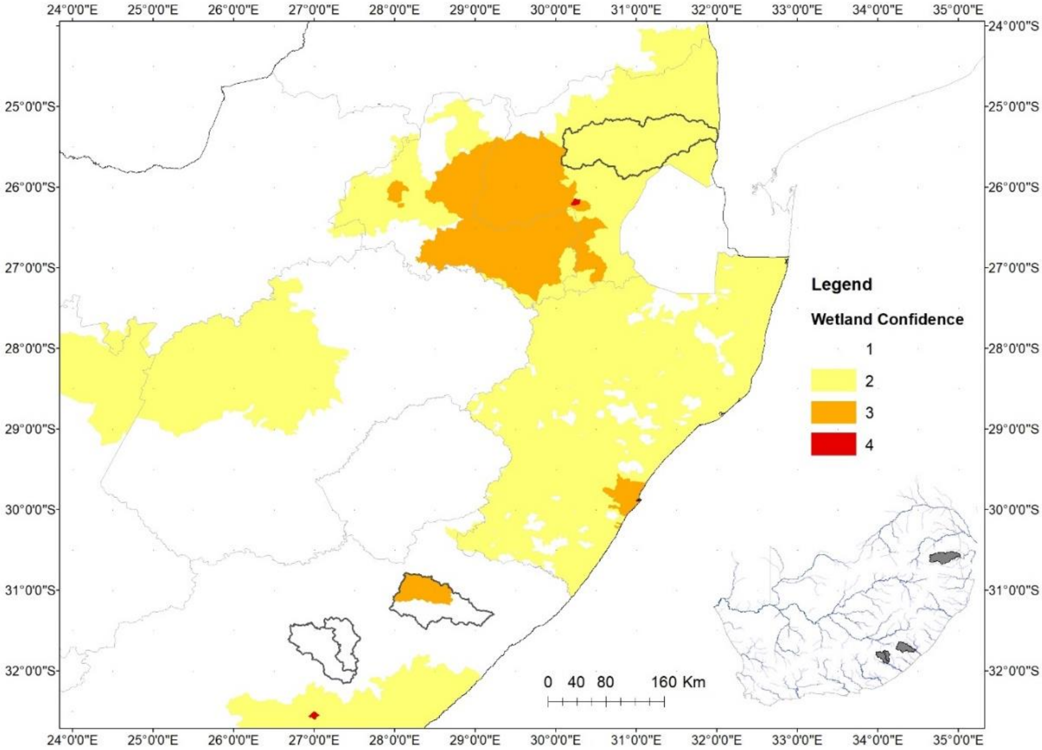


Figure 3-25 Confience level of wetland extent in NWM5 in the area of focal catchments (see text for explanation)

3.2.4.1 Case study 1: White Kei catchment

There are 94 wetlands in the White Kei of which 26 are CR, 61 are EN and 7 are LC as their ETS status (Figure 3-26). Majority of these wetlands are not protected (65), a quarter are poorly protected (26) and only three are moderately protected (Figure 3-27). More than half of the wetlands are in natural/near natural condition (51), and almost equal amounts are moderately modified (18) and largely to severely/critically modified (25) (Figure 3-28).

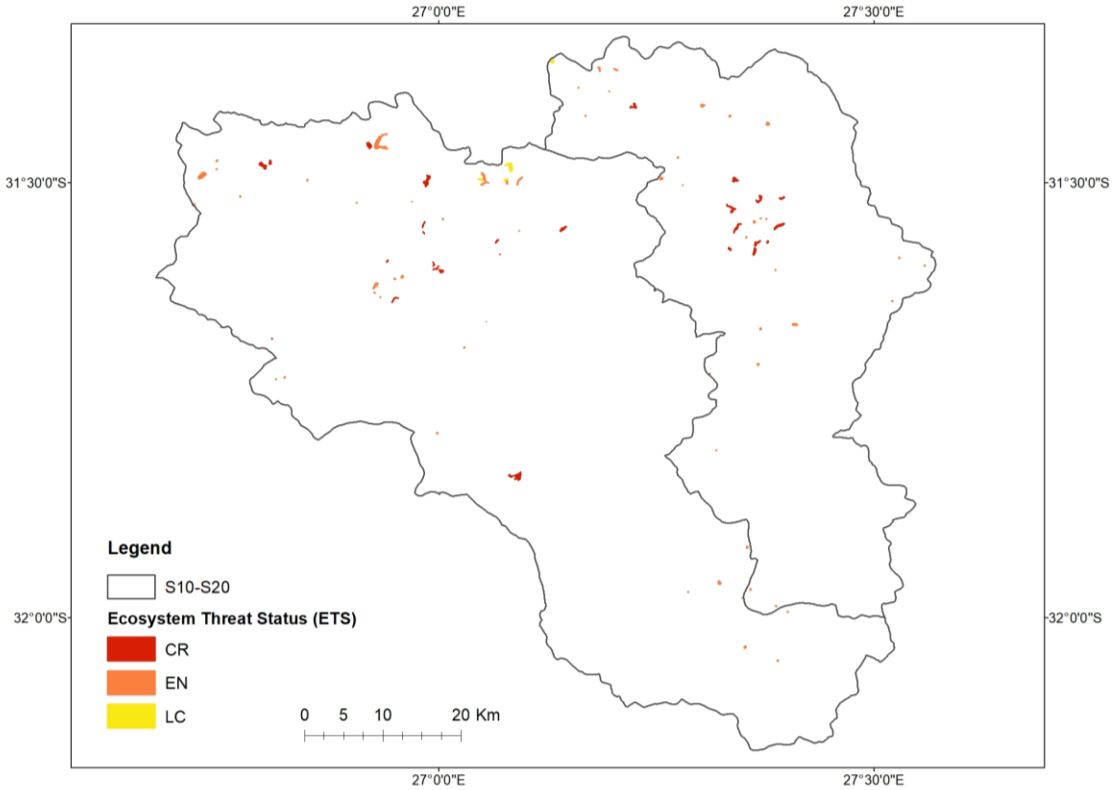


Figure 3-26 Ecosystem Threat Status (ETS) of wetlands defined by NBA 2018 (van Deventer et al., 2019b) in White Kei catchment

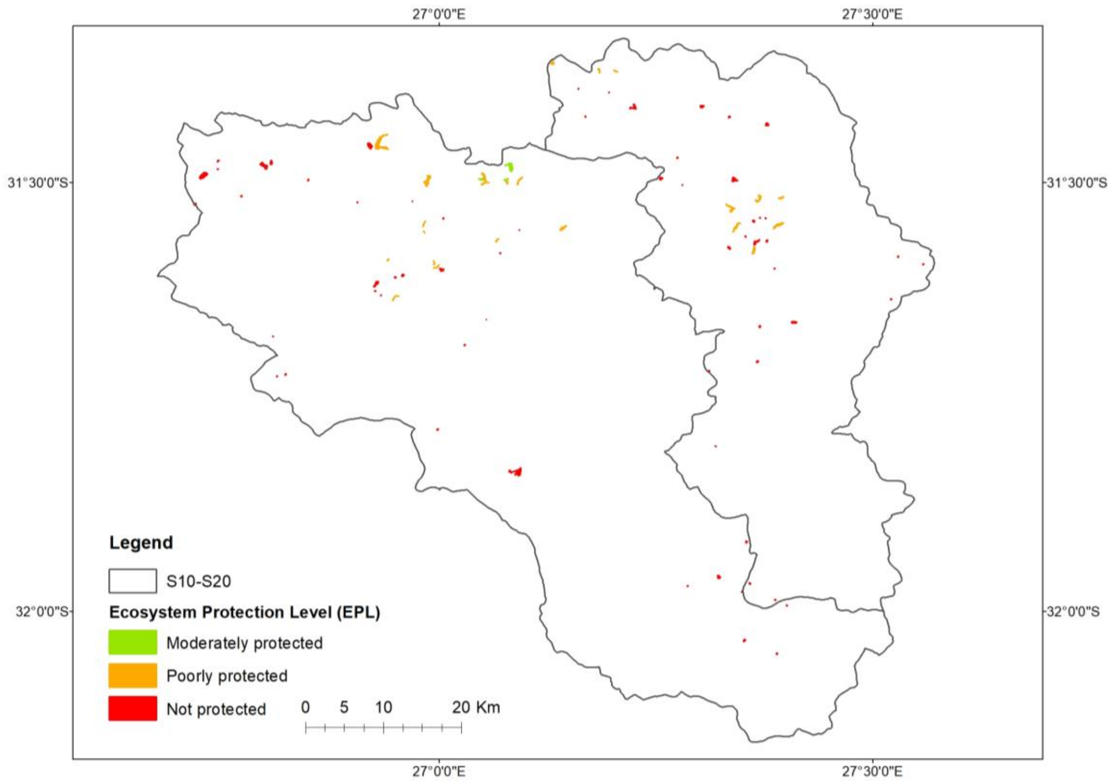


Figure 3-27 Ecosystem Protection Level (EPL) of wetlands defined by NBA 2018 (van Deventer et al., 2019b) in White Kei catchment

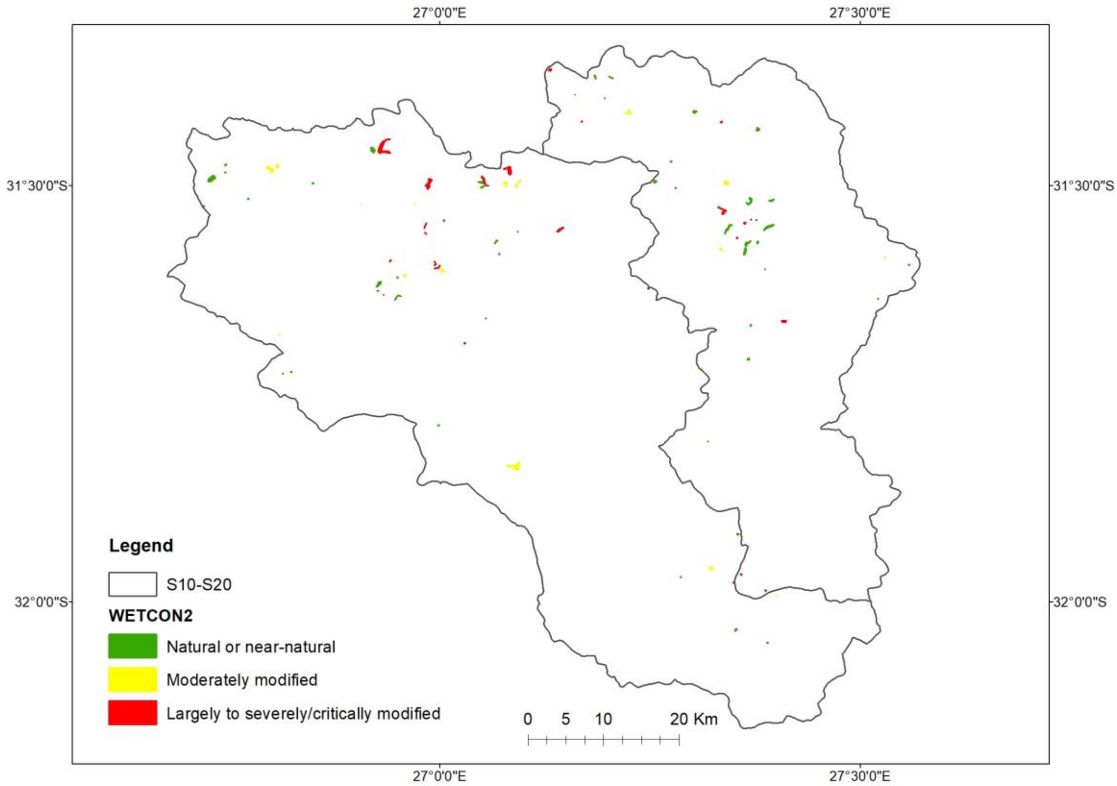


Figure 3-28 Wetland condition defined by NBA 2018 (van Deventer et al., 2019b) in White Kei catchment

3.2.4.2 Case study 2: Tsitsa River catchment

The Tsitsa catchments hosts 3,486 wetlands with the following ETS status: 2,593 are CR, 148 are EN and 745 are LC (Figure 3-29). Majority of these wetlands are not protected (2,442), and almost an equal amount are either poorly protected (451) or moderately protected (593) (Figure 3-30). Almost half of the wetlands are in natural/near natural condition (1,723), but over 32% of the wetlands are largely to severely/critically modified (1,132) and 18% are moderately modified (631) (Figure 3-31).

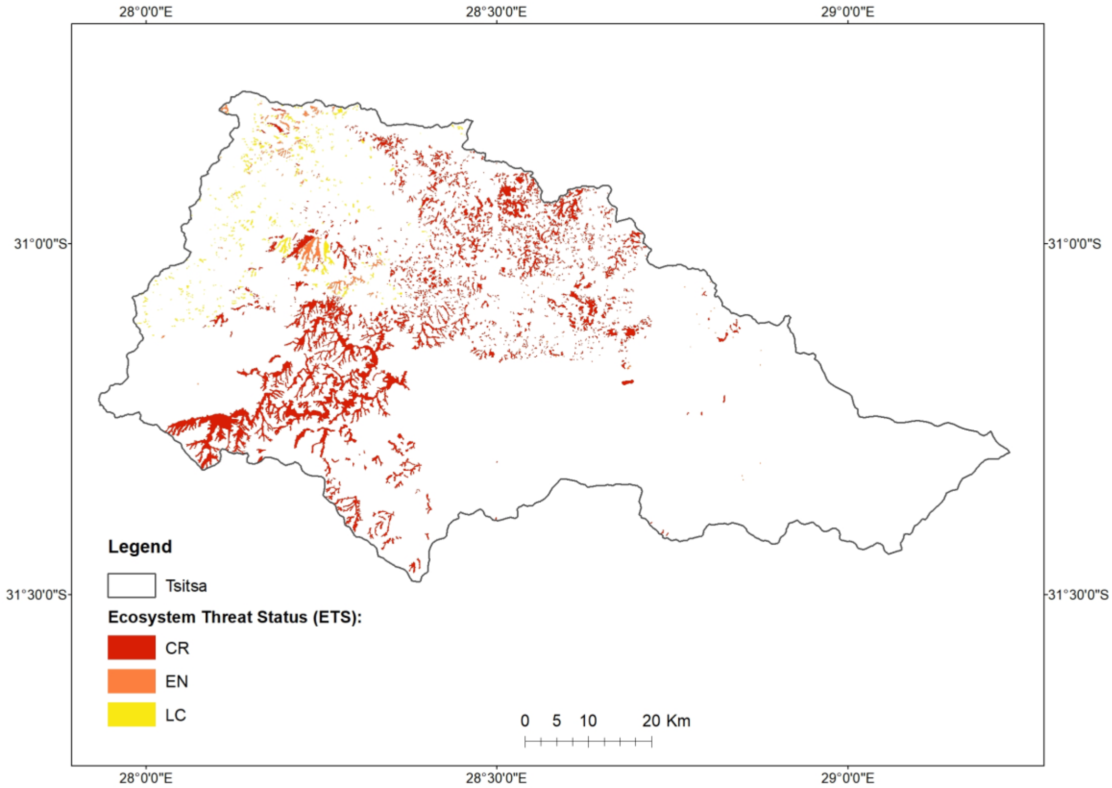


Figure 3-29 Ecosystem Threat Status (ETS) of wetlands defined by NBA 2018 (van Deventer et al., 2019b) in Tsitsa River catchment

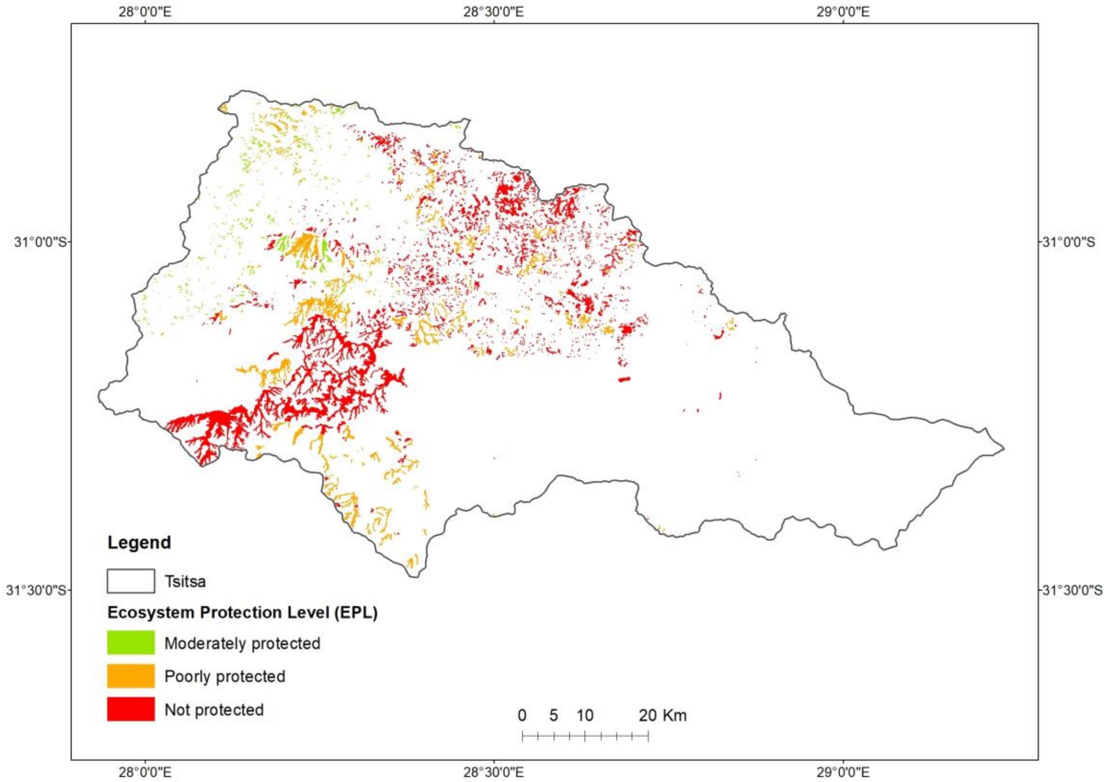


Figure 3-30 Ecosystem Protection Level (EPL) of wetlands defined by NBA 2018 (van Deventer et al., 2019b) in Tsitsa River catchment

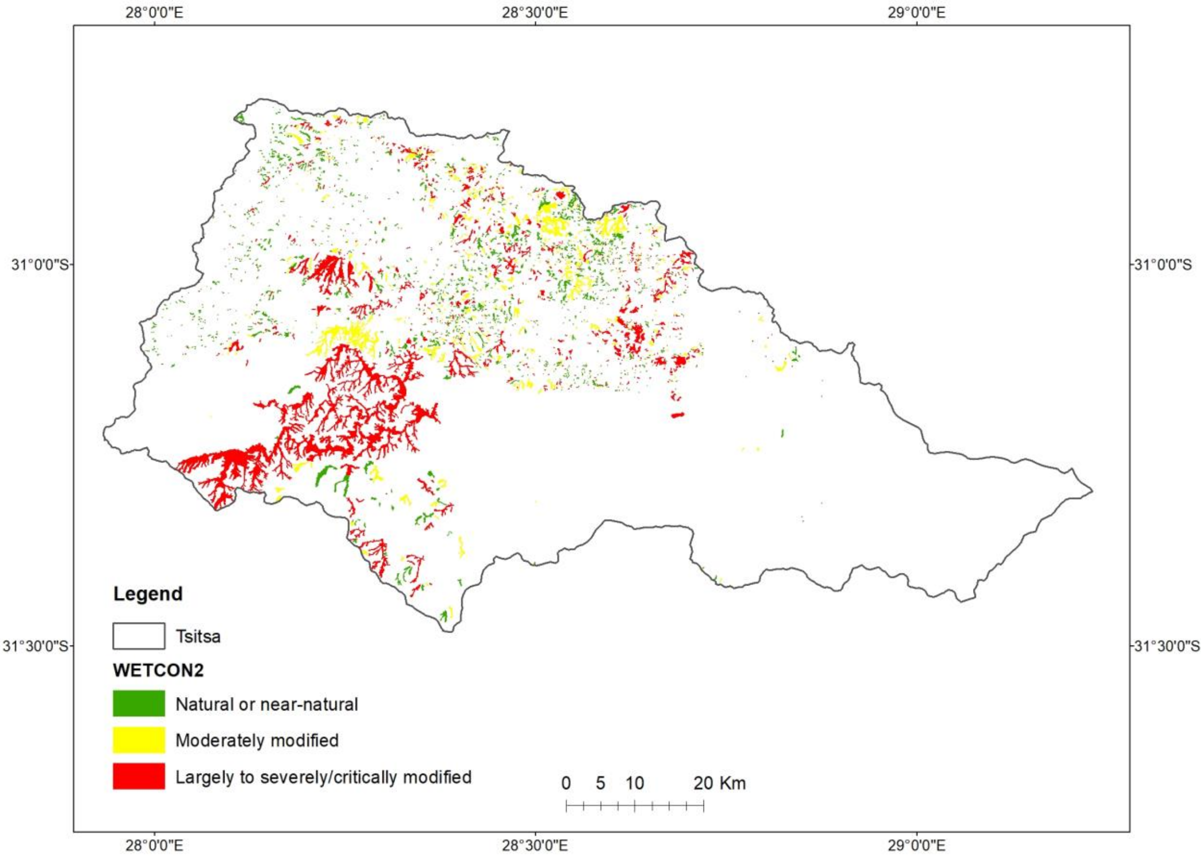


Figure 3-31 Wetland condition defined by NBA 2018 (van Deventer et al., 2019b) in Tsitsa River catchment

3.2.4.3 Case study 3: Crocodile River catchment

There are 1,389 wetlands in the Crocodile catchment according to the NWM5 database; of these, 324 wetlands (all depression type) are located in X21. The ETS status of the Crocodile River wetlands is of concern as over 70% (980) are CR and 5% (70) are EN, 324 wetlands (23%) are vulnerable and 15 wetlands are of least concern (Figure 3-32). A majority of these wetlands are poorly protected (927), 138 wetlands are not protected (451), and only 324 wetlands are well protected (593) (Figure 3-33). Forty-three percent of these wetlands are in natural/near natural condition (596), while an equal amount of the wetlands are either largely to severely/critically modified (403) or moderately modified (390) (Figure 3-34).

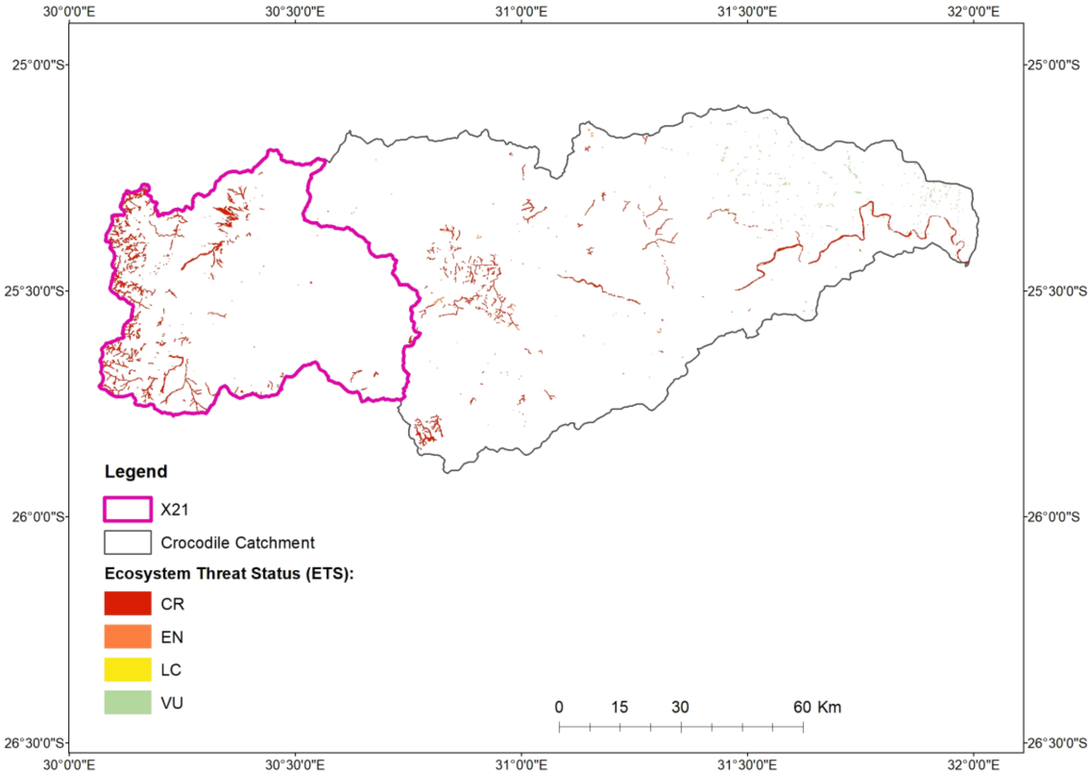


Figure 3-32 Ecosystem Threat Status (ETS) of wetlands defined by NBA 2018 (van Deventer et al., 2019b) in Crocodile River catchment

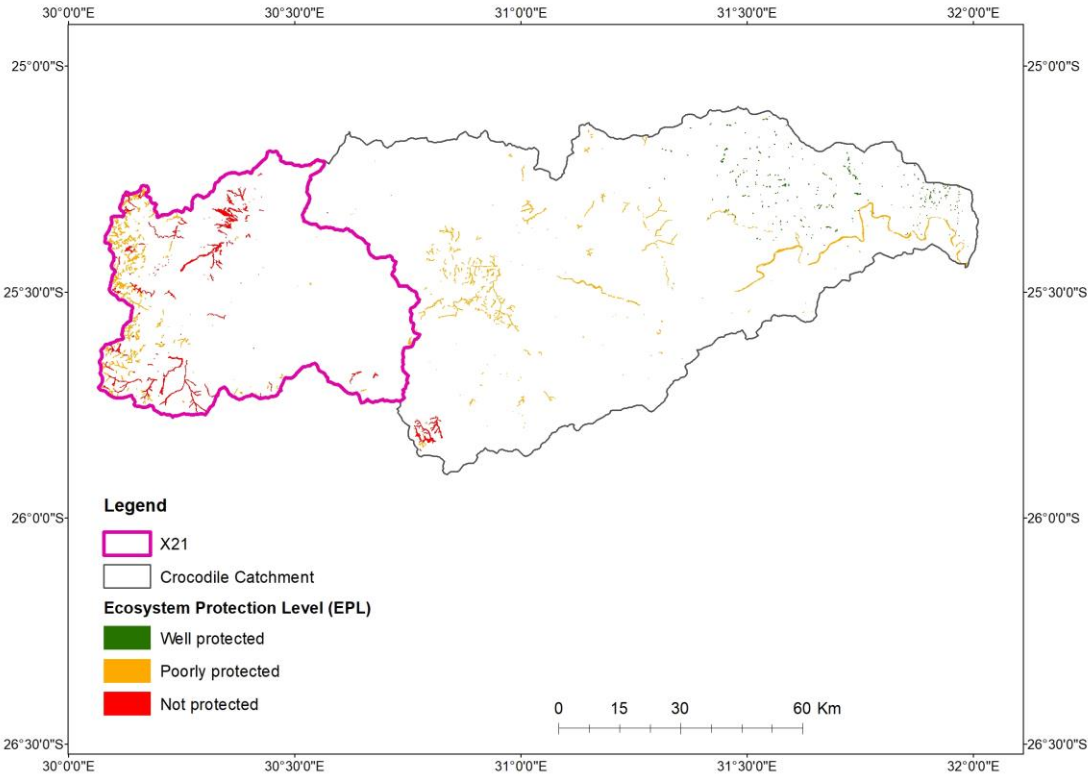


Figure 3-33 Ecosystem Protection Level (EPL) of wetlands defined by NBA 2018 (van Deventer et al., 2019b) in Crocodile River catchment

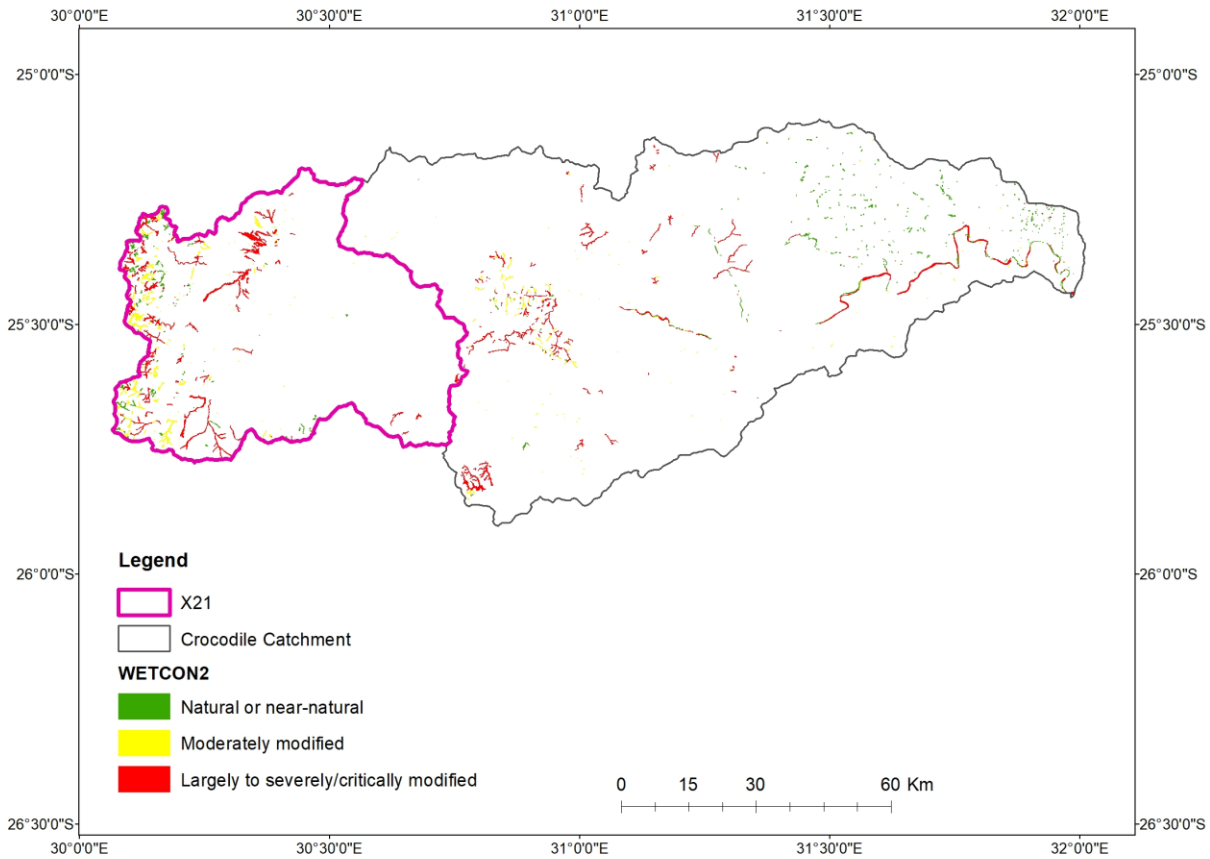


Figure 3-34 Wetland condition defined by NBA 2018 (van Deventer et al., 2019b) in Crocodile River catchment

3.2.5 Land cover change 1990-2018 and 2013-2018

This recently released long-term land cover change assessment provides guidance of where the country is losing its asset and the associated ecosystem services, and thus this analysis informs us of where to focus our efforts to stem the change through prioritisation. Table 3-1 provides a summary of this change at National level and for the two provinces relevant to this project. The Table shows the long- (1990 to 2018) and short-term (2013/14 to 2018) land cover change for five categories (mining, centre pivot agriculture, commercial cultivation, urban and plantations).

Since 1990, the agricultural land cover has expanded three to five fold in the two provinces and nationally (Table 3-1), while over the short term (2013/14 to 2018) the increase has been in the range of 21% to 35%. The Eastern Cape Province has experienced the higher end of increase in agricultural land cover over both the time periods. The total commercial cultivation area and total plantation area in South Africa have also increased by 10% and 31%, respectively over the long-term. Increases in the Eastern Cape have been greater than the national level increases (15% and 52%), while Mpumalanga is close to the national average (13% and 24%) for the 1990 to 2018 period.

Table 3-1 Land cover change statistics (hectares and percent) of significance for national, Eastern Cape and Mpumalanga for long and short term, derived from SANLC change analysis presented in Department of Environmental Affairs (2019: Table 5c)

	National level		Eastern Cape		Mpumalanga	
	ha	%	ha	%	ha	%
1990 to 2018						
Increase in mining footprint	162 942	59%	2 525	38%	50 200	113%
Increase in agricultural land under centre pivots	672 535	279%	56 266	555%	53 606	341%
Increase in total commercial cultivation area	1 273 185	10%	89 378	15%	181 641	13%
Increase in total urban footprint	812 574	30%	98 806	16%	85 397	48%
Increase in total plantation footprint	591 777	31%	79 802	52%	174 897	24%
2013/14 to 2018						
Increase in mining footprint	108 354	34%	2 718	85%	24 815	33%
Increase in agricultural land under centre pivots	164 371	21%	18 315	35%	12 938	22%
Increase in total commercial cultivation area	929 505	19%	67 453	11%	161 226	13%
Increase in total urban footprint	561 377	8%	91 764	15%	46 789	22%
Increase in total plantation footprint	452 724	24%	56 685	37%	125 634	17%

3.3 Land degradation assessment

Land degradation analysis is linked to and informs prioritisation for rehabilitation. The sections below provide the assessment of land degradation in the three focal catchments using the Trends.Earth platform (Conservation International, 2018). Additional details of the analysis are available in the MSc theses by Mr Sinetemba Xoxo and Ms Bawinile Mahlaba. See Box 3-1 for the sub-indicators included in the SDG 15.3.1 land degradation indicator that is calculated by Trends.Earth.

3.3.1 Land degradation assessment background

Land degradation assessment approaches are vital to guide and support land degradation interventions (Easdale et al. 2019; Gonzalez-Roglich et al. 2019). As noted earlier, land degradation has been previously assessed at a national scale based on the status of agricultural land using expert opinions by 453 agricultural experts (Hoffman and Todd, 2000) and using satellite-based NPP (Bai and Dent, 2007). The satellite-based NPP degradation assessment used Rain Use Efficiency (RUE) and Residual Trend Analysis adjusted NDVI at 1 km spatial resolution as proxies to measure degradation (Wessels et al., 2007; Tucker, 1979; Bai and Dent, 2007). Bai et al*.*'s (2007) results were later verified by Bai and Dent (2008) using field visits.

Box 3-1 SDG 15.3.1 Land degradation indicator assessment by Trends.Earth

The SDG 15.3.1 indicator aims "*to monitor the proportion of land that is degraded over the total land area*". This indicator aligns with our project's focus of identifying land degradation.The SDG 15.3.1 degradation indicator defines three key sub-indicators :

- **land productivity**: refers to the biological capacity of the land to produce, and it represents the source of all food, fibre and fuel that sustains humans
- **land cover**: is the visible physical and biological terrestrial cover of the Earth, and changes in land cover can identify land degradation
- **soil organic carbon**: contributes towards increasing resilience of land and populations dependent on the land

These sub-indicators are proxies for monitoring key factors and driving variables for assessing the delivery of ecosystem services (Orr et al., 2017), and this makes the indicator SDG15.3.1 more comprehensive in its evaluation of land degradation.

Recently, Sims et al. (2017) have generated a comprehensive guidance document for assessing the SDG 15.3.1 indicator, which aims "*to monitor the proportion of land that is degraded over the total land area*". This indicator aligns with our project's focus of identifying land degradation and for input into the rehabilitation prioritisation of the targeted EI land covers. The indicator SDG15.3.1 has three key sub-indicators, namely land productivity, land cover and soil organic carbon (Sims et al., 2017; Orr et al., 2017; Sims et al., 2019).

Land productivity, the first sub-indicator, refers to the biological capacity of the land to produce, and it represents the source of all food, fibre and fuel that sustains humans (Sims et al., 2017: p. 38). The land productivity sub-indicator is based on the concept that the loss of vegetation productivity is linked to land degradation (Munyati and Ratshibvumo, 2011; Landmann and Dubovyk, 2014), and these studies utilised remote sensing imagery to evaluate the degradation.

The second sub-indicator, land cover, is the visible physical and biological terrestrial cover of the Earth, and changes in land cover can identify land degradation. According to Sims et al. (2017: p. 8), this sub-indicator can also feed into the evaluation of SDG indicators 6.6.1 (change in extent of water-related ecosystems over time), 11.3.1 (land consumption rate to population growth rate) and 15.1.1 (forest area as percent of total land area).

The third sub-indicator for SDG 15.3.1, soil organic carbon (SOC), contributes towards increasing resilience of land and populations dependent on the land. The loss of SOC contributes to reduced soil quality and fertility, which can impact water infiltration, soil biodiversity, erosion and agricultural yields (Sims et al., 2017); soils have been labelled as ‘dark matter’ biodiversity (Beach, Luzzadder-Beach and Dunning, 2019). Soil organic carbon stocks are influenced mainly by land-use and management choices that affect nutrient input and output rates (Mills and Fey, 2003). According to the South African National Terrestrial Carbon Sink Assessment, over 60% of the terrestrial SOC stock is hosted by the grassland and savanna ecosystems, stressing the importance of planning and managing spatial changes in these two biomes (Department of Environmental Affairs, 2015b).

3.3.2 Trends.Earth for assessing SDG indicator 15.3.1

(Conservation International, 2018) recently produced the Trends.Earth plugin for QGIS software, which allows determination of the SDG 15.3.1 indicator. The project supported MSc students used this plugin for evaluating the SDG 15.3.1 indicator for the three project focal catchments and the sections below present the results of their research.

The Trends.Earth plugin was developed as part of the Global Environmental Facility initiative to extend the availability and the use of global data sources to study land degradation at multiple scales (Conservation International, 2018). The plugin has been utilised in several locations for vegetation productivity measures and land degradation evaluation in South African drylands (Hoffman et al., 2018), for land degradation neutrality assessment at a global scale (Gonzalez-Roglich et al., 2019), and to assess the potential of earth observation datasets to estimate degradation in Namibia (Mariathasan, Bezuidenhoudt and Olympio, 2019). Table 3-2 provides a summary of the satellite datasets used in the plugin for the present study.

Table 3-2 Datasets used to estimate land degradation and SDG 15.3.1 sub-indicators through Trends.Earth (see text for details)

Dataset	Spatial resolution	Temporal scale	Temporal Coverage
ESA CCI-LC [a]	300 m	Annually	1992 to 2015
SOILGRIDS250m [b]	250 m	Annually	2000 to 2015
MOD13Q1 [c]	250 m	16 days	2000 to Present
CHIRPS [d]	5 km	Monthly	1981 to Present

[a] European Space Agency Climate Change Initiative (ESA CCI-LC) – the recent version (version 2.0.7) of global annual integral land cover (https://www.esa-landcover-cci.org/).

[b] SOILGRIDS250: A 3D system for global soil information based on spatial predictions of soil properties at various depths (Hengl et al., 2017).

[c] MODIS MOD13: A 250 m resolution bi-monthly MODIS derived NDVI at a global scale (https://modis.gsfc.nasa.gov/data/dataprod/mod13.php).

[d] CHIRPS: A global precipitation dataset derived from 5 km resolution quasi-global surface rainfall gauge analysis and spatial datasets (Funk et al., 2015).

The land productivity sub-indicator was estimated using the 16-day 250 m MODIS (Moderate Resolution Imaging Spectroradiometer) satellite dataset (MOD13Q1) to derive NDVI values as a land productivity proxy (Table 3-2). The plugin option to remove climate bias was used to derive a Rain Use Efficiency adjusted NDVI that provides a better representation of human-induced impacts (Wessels et al., 2007; Wessels, Van den Bergh and Scholes, 2012). The precipitation dataset used to remove the climate bias was obtained from the Climate Hazards group Infrared Precipitation with Stations (CHIRPS) (Funk et al., 2015). The CHIRPS dataset is based on a combination of local rainfall station data with remotely sensed infrared cloud cover data from the quasi-global area (50°S to 50°N).

The land cover for the second sub-indicator was derived using the European Space Agency: Climate Change Initiative (ESA CCI) for Global Land Cover at 300 m resolution by classifying the baseline (year 2000) and the target (year 2015) datasets (Table 3-2). The 36 classes of the ESA CCI dataset were combined to obtain the seven land cover classes recommended by UNCCD, and these are used for the land cover change assessment. The third sub-indicator of SOC stocks used the plugin's default option to estimate the topsoil SOC stocks that were derived from the SoilGrids250m project (Hengl et al., 2017) over the years 2001 to 2015.

The plugin allows flexibility in terms of defining the land cover class transitions that are considered to be either degradation or improvement depending on the context of the research area. Thus, for our project the land cover transition criteria were user-defined (Table 3-3) so as to capture land degradation in grassland and savanna biomes based on South African literature on whether the transition would be considered as positive / improvement or negative / degradation (Le Maitre, Kotzee and O'Farrell, 2014; Stafford et al., 2017; Luvuno et al., 2018; Gibson et al., 2018; Scorer, Mantel and Palmer, 2018). As an example, grasslands converting to a tree-covered area is considered as a negative change, since it is generally encroachment by woody species (Luvuno et al., 2018). Conversely, tree-covered areas transforming to grasslands have been classified as grassland re-establishment as generally it is conversion from woody encroached or invaded areas (Mograbi et al., 2015), potentially by the WfW programme. Cropland areas are most vulnerable to invasion, and thus, a change from cropland to trees is also defined as a negative change (Münch et al., 2017; Scorer, Mantel and Palmer, 2018), although there is a possibility for passive restoration of croplands (Benayas et al., 2007). Wetlands converting to croplands or invasive plants is defined as degradation (Rebelo et al., 2015), while any artificial area (man-made structure) converting to any of the natural land covers is considered as an improvement (Richardson et al., 2000).

Table 3-3 A matrix of changes, which shows the land degradation definition used for the transitions. Land cover state transitions are highlighted as degradation (red), stable (amber), or improvement (green).

2000 \ 2015	Tree-covered	Grassland	Cropland	Wetland	Artificial	Bare land	Water bodies
Tree-covered	Stable	**Vegetation establishment**	**Agricultural expansion**	Wetland establishment	Deforestation	Vegetation loss	Inundation
Grassland	Woody encroachment	Stable	Loss of vegetation	Wetland establishment	Urban expansion	Vegetation loss	Inundation
Cropland	Woody encroachment	**Withdrawal of agriculture**	Stable	Wetland establishment	Urban expansion	Vegetation loss	Inundation
Wetland	Woody encroachment	Wetland drainage	Wetland drainage	Stable	Wetland drainage	Wetland drainage	**Inundation**
Artificial	**Afforestation**	Vegetation establishment	Agricultural expansion	Wetland establishment	Stable	Withdrawal of settlements	Inundation
Bare land	**Afforestation**	Vegetation establishment	Agricultural expansion	Wetland establishment	Urban expansion	Stable	Inundation
Water bodies	Afforestation	Dry-up	Draining	Wetland establishment	Urban expansion	Dry-up	Stable

Finally, to compute the SDG 15.3.1 land degradation indicator from the three sub-indicators, the plugin combines them following the *one-out all-out* rule (Conservation International, 2018), meaning that a pixel is considered to be degraded, if any of the three sub-indicators are degraded at that location. Improvement can be attained when all three sub-indicators improve or one or two of the sub-indicators are stable, and the rest are improved. A stable result for SDG 15.3.1 indicator can only be attained when all three sub-indicators are categorised as stable.

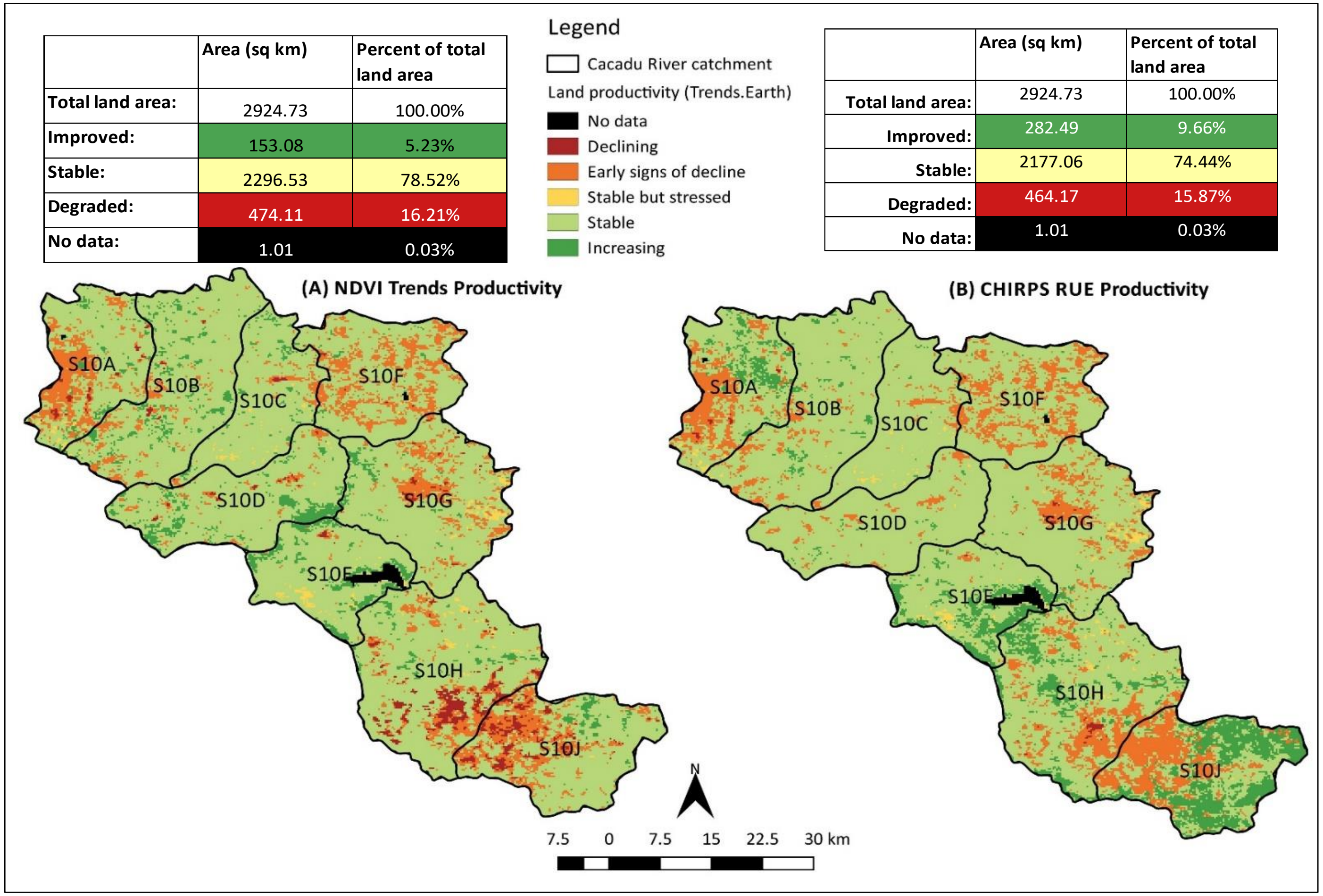
3.3.3 Results for SDG15.3.1 degradation indicator for Cacadu catchment (S10)

3.3.3.1 Sub-indicator 1: Land productivity in Cacadu River catchment

Figure 3-35 illustrates the land productivity results for NDVI trends for Cacadu River catchment. The NDVI trends outcome without climate correction (Figure 3-35a) noticeably underestimated the improving land productivity status by 4.43% compared to the RUE adjusted outcome and overestimated the declining land productivity status by a negligible 0.34% (Figure 3-35b). Comparison of the two figures suggests similar trends for the declining state, but conflicting observations for the improving trends, particularly for some quaternary catchments (e.g. S10A, C, D, E, H and J). Both outcomes indicate a considerable proportion (approx. 78.5% and 74.4%) of the Cacadu River catchment conditions to be stable, but under the RUE correction scenario, the estimates show an apparent greening status. The RUE adjusted productivity showed less area with declining state.

3.3.3.2 Sub-indicator 2: Land cover change in Cacadu River catchment

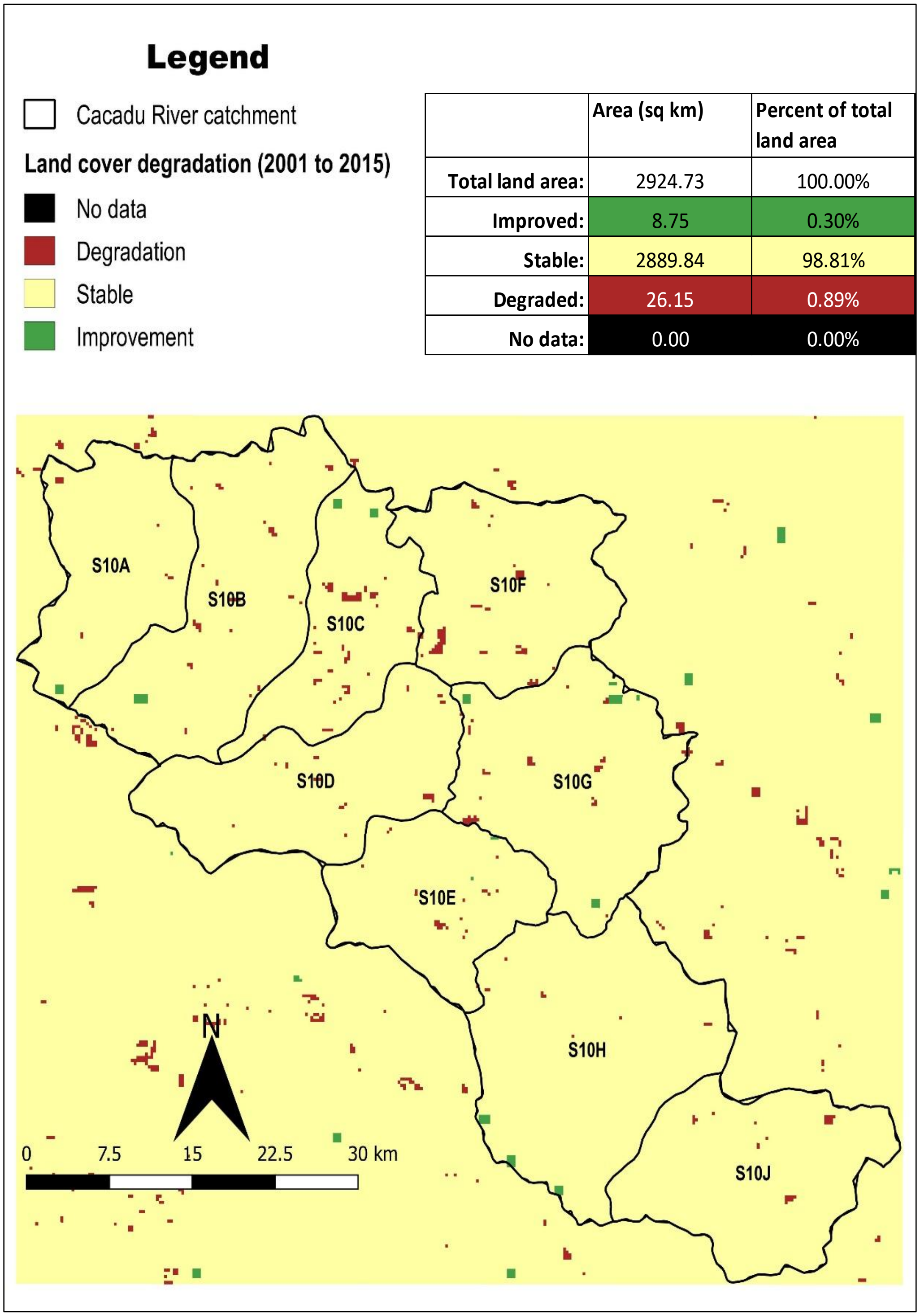
Land cover change from 2001 to 2015 in the Cacadu River (Figure 3-36) indicates a significant proportion of the area (above 98%) as stable, with a few pixels showing loss in tree-cover or grasslands. The grassland loss and tree-cover increase detected by the plugin was less than 1% for these land cover categories (Table 3-4). The Table indicates that the artificial areas expanded by over 280% (from an initial area of 0.32 km^2) during the 15 years since 2000. No land cover transition was detected for both wetlands and croplands (Figure 3-36, Table 3-4). The summary Table of land cover change in Figure 3-36 also indicates a negligible amount of improvement (0.45%) and degradation (0.56%).



	Area (sq km)	Percent of total land area
Total land area:	2924.73	100.00%
Improved:	153.08	5.23%
Stable:	2296.53	78.52%
Degraded:	474.11	16.21%
No data:	1.01	0.03%

	Area (sq km)	Percent of total land area
Total land area:	2924.73	100.00%
Improved:	282.49	9.66%
Stable:	2177.06	74.44%
Degraded:	464.17	15.87%
No data:	1.01	0.03%

Figure 3-35 Land productivity in Cacadu River catchment for the years 2001 to 2015. Land productivity result (a) Left: without correction for climate influence, and (b) Right: with climate correction using the rain use efficiency index. The percent land area presented in the Table are in three groups: Improved = Increasing, Stable = Stable, and Degraded = Stable but stressed + Early signs of decline + Declining



	Area (sq km)	Percent of total land area
Total land area:	2924.73	100.00%
Improved:	8.75	0.30%
Stable:	2889.84	98.81%
Degraded:	26.15	0.89%
No data:	0.00	0.00%

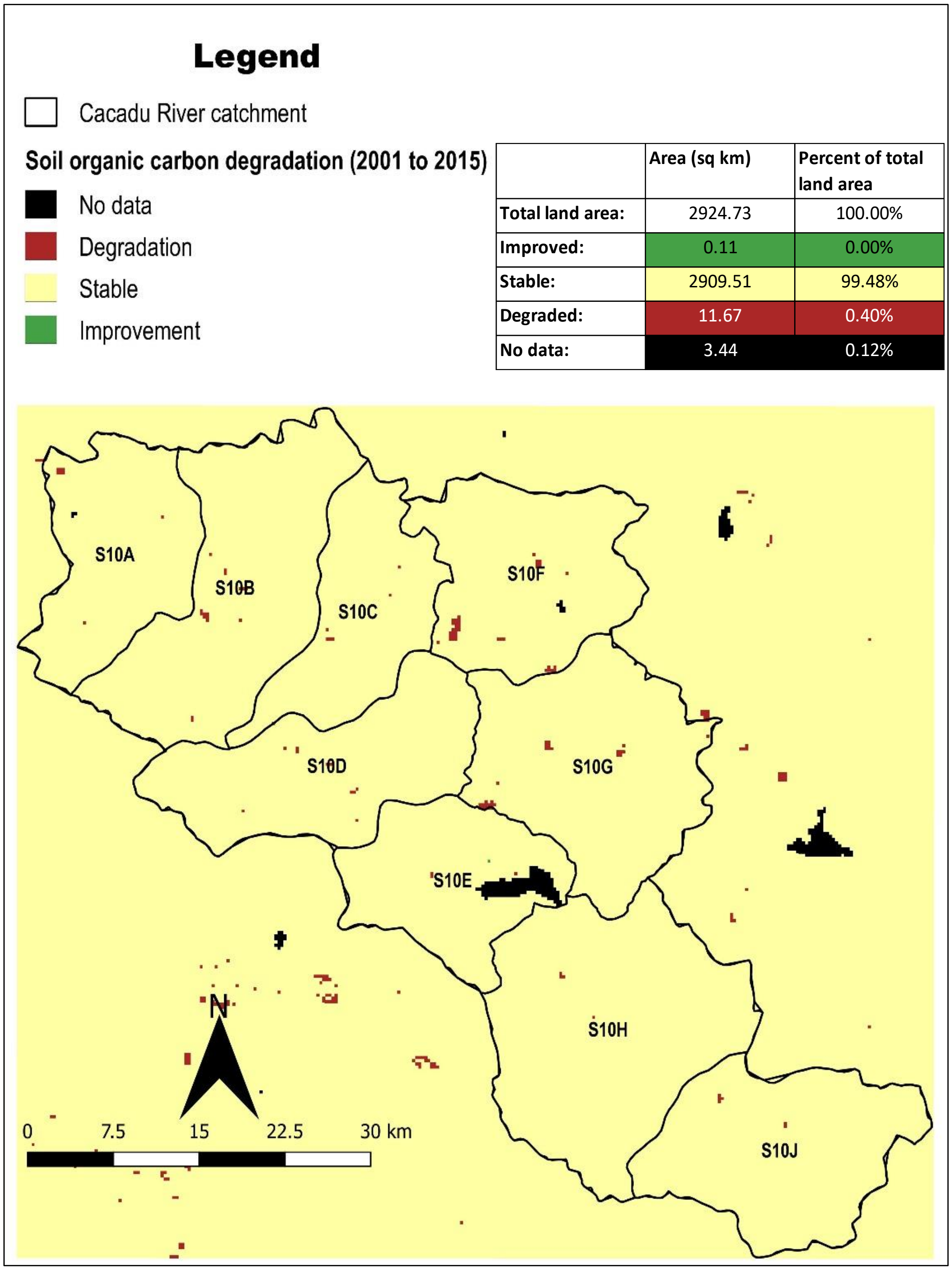
Figure 3-36 Land cover change for Cacadu River catchment between 2001 and 2015. The Table shows summary of change in land cover

Table 3-4 Matrix showing Cacadu catchment land area by type of land cover transition (km^2). Rows represent land cover classes in the year 2001, and columns represent land cover classes in the year 2015, and fill colour represents the land cover change definition.

UNCCD land cover groups	Tree-covered	Grasslands	Croplands	Wetlands	Artificial	Other lands	Water bodies
Tree-covered	141.75	8.69	0.00	0.00	0.37	0.00	0.00
Grasslands	9.65	2 447.71	15.49	0.00	0.53	0.11	0.00
Croplands	0.00	0.00	298.00	0.00	0.00	0.00	0.00
Wetlands	0.00	0.00	0.00	0.11	0.00	0.00	0.00
Artificial areas	0.00	0.00	0.00	0.00	0.32	0.00	0.00
Other lands	0.00	0.05	0.00	0.00	0.00	1.96	0.00
Water bodies	0.00	0.00	0.00	0.00	0.00	0.00	15.52

3.3.3.3 Sub-indicator 3: Soil organic carbon in Cacadu River catchment

Comparison of average SOC stocks indicated no significant change in any of the land cover types from 2001 to 2015 with over 99% of land area showing stable conditions (Figure 3-37). Wetlands and tree-covered areas had more initial SOC stocks in comparison to the other land cover classes, while croplands and other lands had the lowest SOC stocks (data not shown here).

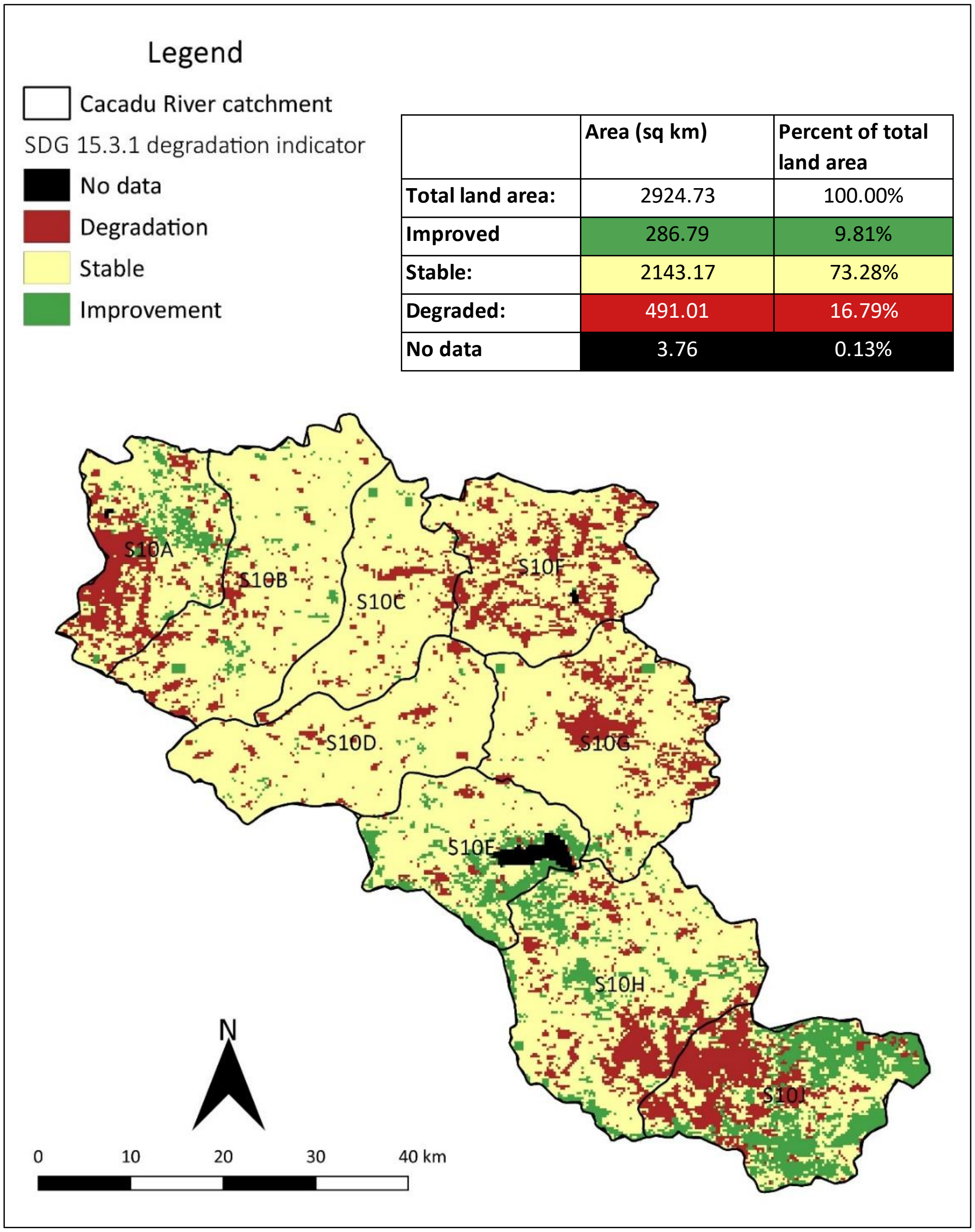


	Area (sq km)	Percent of total land area
Total land area:	2924.73	100.00%
Improved:	0.11	0.00%
Stable:	2909.51	99.48%
Degraded:	11.67	0.40%
No data:	3.44	0.12%

Figure 3-37 Soil organic carbon change in Cacadu River catchment for the assessment period covering the years 2001 to 2015

3.3.3.4 SDG 15.3.1: Proportion of land degraded in Cacadu River catchment

Most of the pixels (over 73%) represent a stable state in the landscape, and 10% of the landscape improved (Figure 3-38). The proportion of land area which degraded over the assessment period was <17% degraded area; thus, the S10 catchment could be classified as experiencing low to moderate degradation intensity over the assessment period. This low proportion of degraded area could be because of the short and recent period of evaluation (2001 to 2015). A study in South Africa that compared the results of World Overview of Conservation Approaches and Technologies (WOCAT; https://www.wocat.net/en/) perception-based land degradation with land productivity mapping using remote sensing, noted that degraded areas identified by remote sensing did not correlate well with the perceptions of degradation on the ground (von Maltitz et al., 2019). The authors proposed various reasons for this including the fact that a significant amount of degradation occurred before the availability of satellite products. We similarly suggest that in our study catchment the degradation happened decades ago when people were moved to the homelands during the apartheid era, or possibly even earlier than that. Secondly, the recent decades with a trend towards rural depopulation may even have decreased pressure on the rangelands. Another reason for the small area found to be degraded is that grassland degradation begins with a shift in grass species composition, particularly a shift towards dominance by non-palatable species. This shift cannot be detected by the methods, such as NDVI, used by Trends.Earth. Thus, remote sensing tools would only detect degradation at a later point in time when the vegetation growth has been affected.



	Area (sq km)	Percent of total land area
Total land area:	2924.73	100.00%
Improved	286.79	9.81%
Stable:	2143.17	73.28%
Degraded:	491.01	16.79%
No data	3.76	0.13%

Figure 3-38 Patterns of human-induced land degradation (SDG 15.3.1 degradation indicator) in Cacadu River catchment for the assessment period covering the years 2001 to 2015

3.3.4 Results for SDG15.3.1 degradation indicator for Tsitsa River catchment (T35)

3.3.4.1 Sub-indicator 1: Land productivity in Tsitsa River catchment

Land productivity results for T35 catchment without climate correction indicate that 41% of the catchment is experiencing degradation, while 45% of the total land area is stable (Table in Figure 3-39). Land with degraded productivity or showing early signs of decline in productivity are in the upper catchment. The middle part of the catchment is primarily stable or has improved land productivity, while the lower parts of the catchment show early signs of decline in productivity.

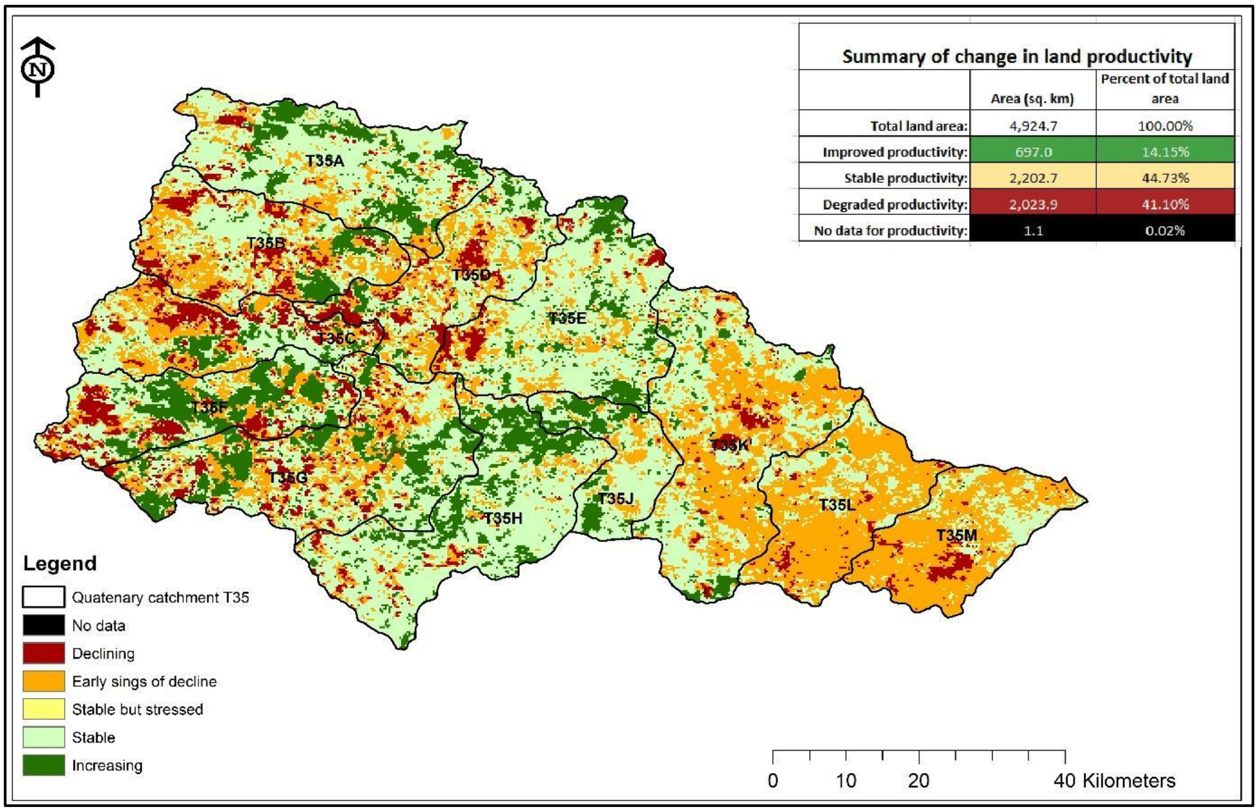


Figure 3-39 Land productivity in Tsitsa River catchment for the years 2001 to 2015 without correction for climate influence. The percent land area presented in the Table are in three groups: Improved = Increasing, Stable = Stable, and Degraded = Stable but stressed + Early signs of decline + Declining

The results for land productivity with climate correction (using RUE method) show that areas that were classified as declining in land productivity without climate correction (Figure 3-39) are classified as having early signs of decline with climate correction (Figure 3-40). Land productivity in the catchment for the years 2000-2015 with climate correction found ~5% of the land area had improved, 55% was stable and 40% had degraded over this time period (Table in Figure 3-40).

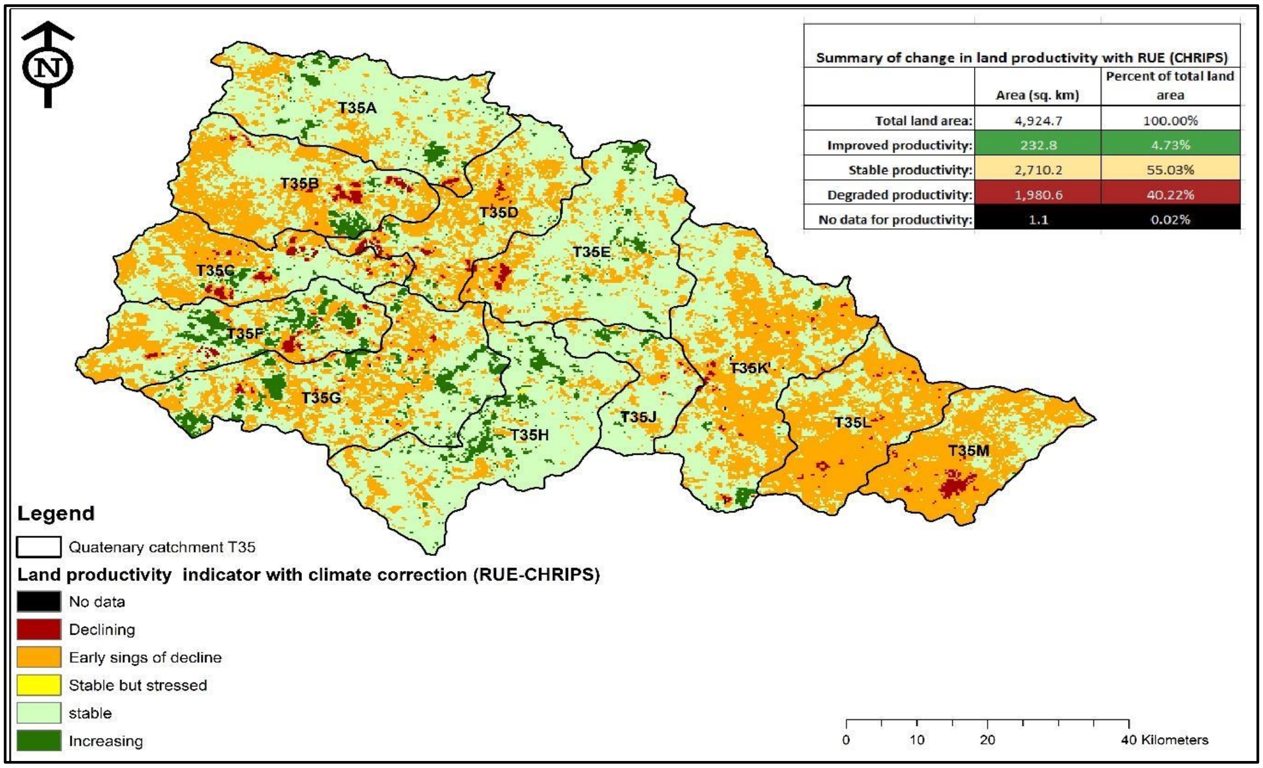


Figure 3-40 Land productivity in Tsitsa River catchment for the years 2001 to 2015 with correction for climate influence. The percent land area presented in the Table are in three groups: Improved = Increasing, Stable = Stable, and Degraded = Stable but stressed + Early signs of decline + Declining

3.3.4.2 Sub-indicator 2: Land cover change in Tsitsa River catchment

The results for land cover change indicate that a majority of the land cover (98.4%) in the area was stable from 2001 to 2015, and improved land cover occurred for just over 1% of the area (Table in Figure 3-41). Only 0.33% of the upper catchment was degraded according to this sub-indicator. The major land cover transition in the catchment was the loss of tree covered areas (~6% loss), in the upper catchment (primarily T35A, T35B, T35F, T35G). The results show increase in the artificial areas (over 19% gain), wetlands (increase of 4%), grasslands (increase of 1%) and croplands (0.64% increase). No change was observed in land cover categories 'other lands' and 'water bodies'.

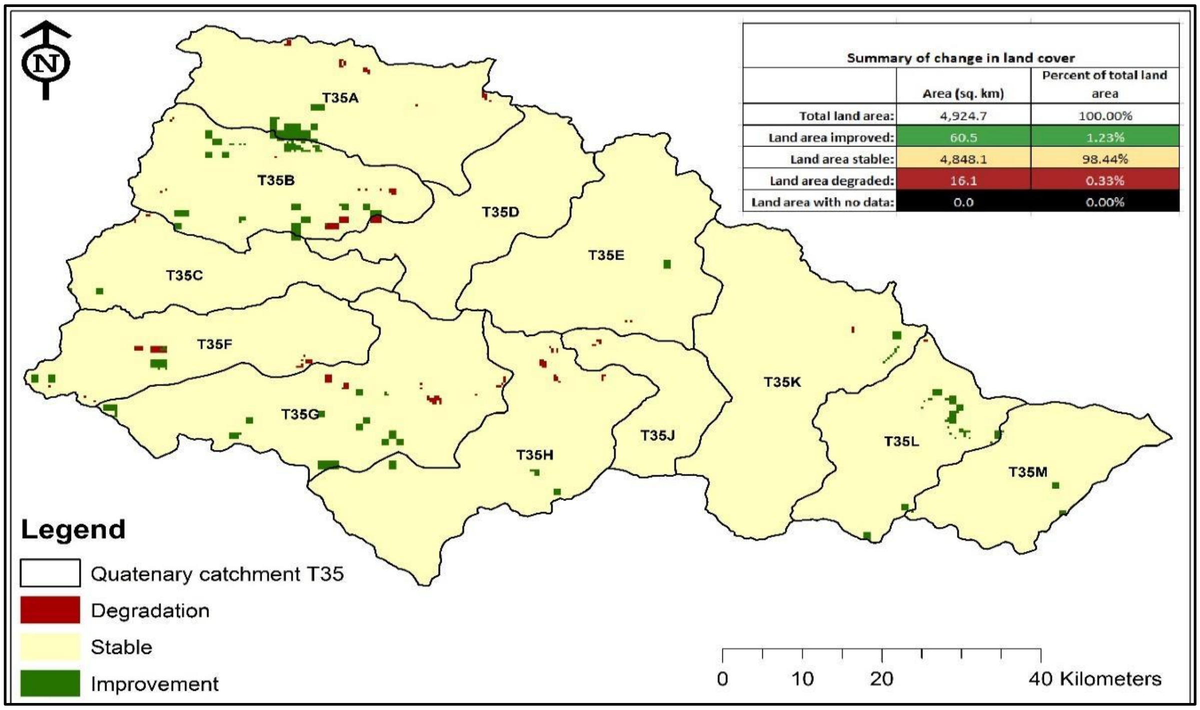


Figure 3-41 Land cover change for the Tsitsa River catchment between 2001 and 2015. The Table shows summary of change in land cover

3.3.4.3 Sub-indicator 3: Soil organic carbon in Tsitsa River catchment

The results of soil organic carbon indicated that 99.9% of the land area had stable SOC, and a negligible amount of the land area showed improved or degraded SOC. The results for SOC thus indicate that the catchment has not degraded in terms of SOC over the assessment period.

3.3.4.4 SDG 15.3.1: Proportion of land degraded in Tsitsa River catchment

The Trends.Earth results for SDG15.3.1 degradation indicator (which incorporates all three sub-indicators based on the *one-out all-out* rule) with climate correction showed that 54% of the catchment was stable, 41% of the land had degraded and 5% of land area had improved (Table in Figure 3-42). The moderately high amount of human-induced land degradation is widespread in the upper and lower parts of the catchment, compared to the middle part of the catchment, which was mainly stable. This degradation is primarily linked to an increase in artificial areas.

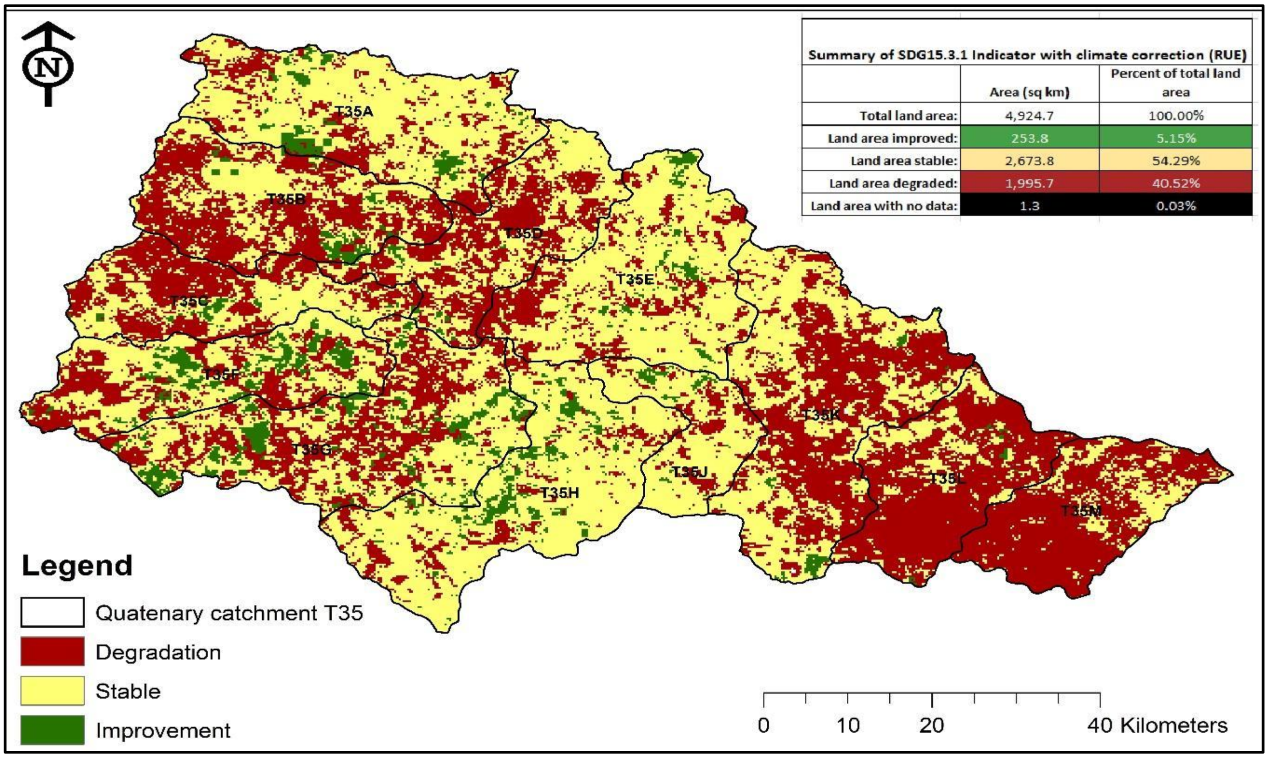


Figure 3-42 Patterns of human-induced land degradation (SDG 15.3.1 degradation indicator) in Tsitsa River catchment for the assessment period covering the years 2001 to 2015

3.3.5 Results for SDG15.3.1 degradation indicator for Crocodile River catchment (X21)

3.3.5.1 Sub-indicator 1: Land productivity in Crocodile River catchment

The Trends.Earth analysis was conducted for X21, upper catchment of the Crocodile River catchment. Both indices show that over 50% of the Upper Crocodile catchment was stable, but the RUE-corrected land productivity detected 12% more stable pixels (33.97% versus 21.94%; see Tables in Figure 3-43). Additionally, many of the 'Stable but stressed' category areas are classified as 'Declining' with RUE adjustment (Figure 3-43b). At a catchment scale, Figure 3-43a shows four dominant biomass productivity dynamics (stable, improving, declining, and early signs of decline), compared to Figure 3-43b which shows three dominant productivity states (stable, early signs of decline, and declining).

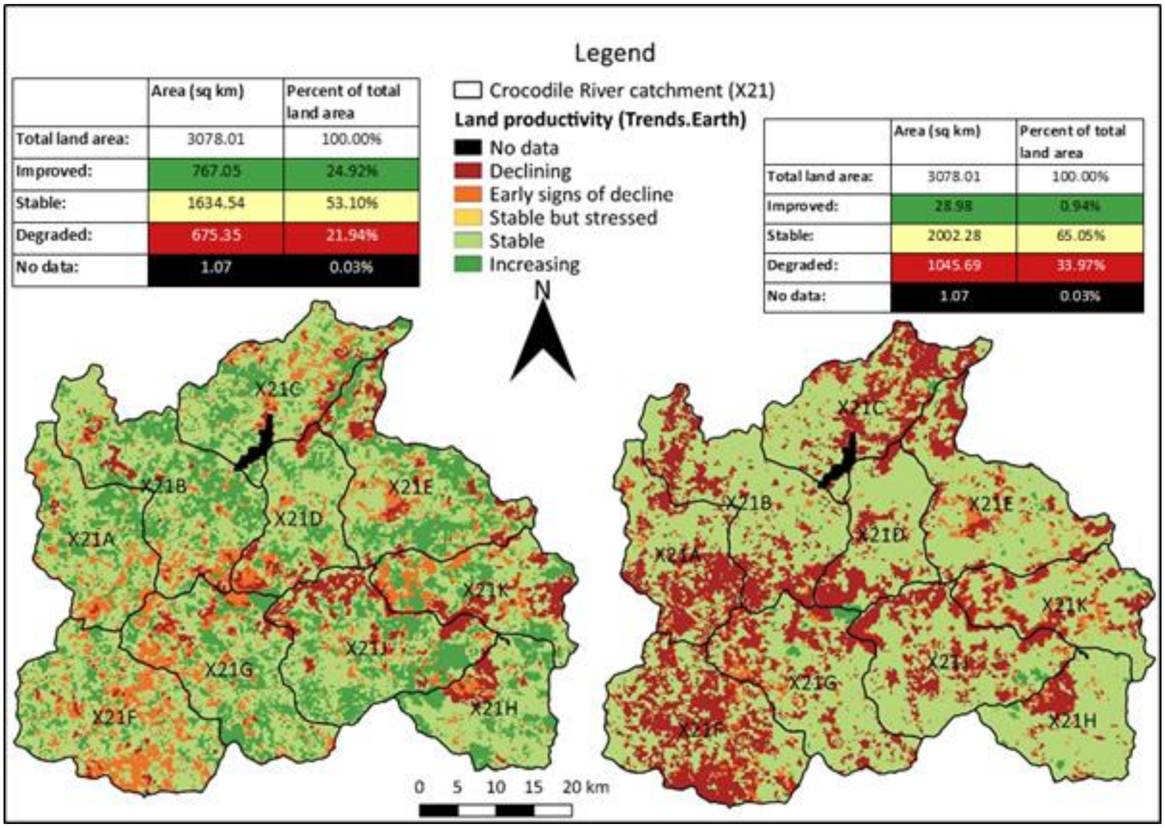


Figure 3-43 Land productivity in the Crocodile River catchment for the years 2001 to 2015. Land productivity result (a) Left: without correction for climate influence, and (b) Right: with climate correction using the rain use efficiency index. The percent land area presented in the Table are in three groups: Improved = Increasing, Stable = Stable, and Degraded = Stable but stressed + Early signs of decline + Declining

3.3.5.2 Sub-indicator 2: Land cover change in Crocodile River catchment

A large proportion of the area across all land cover classes (above 99%) was found to be stable over the 15 years (Figure 3-44a), but some pixels indicated a loss of tree-cover, croplands and wetlands in some quaternary catchments (results not shown). Notably, no land cover transition was detected for water bodies. The summary Table of land cover change in Figure 3-44a also indicated a negligible amount of improvement (0.49%) and degradation (0.40%).

3.3.5.3 Sub-indicator 3: Soil organic carbon in Crocodile River catchment

The total change in SOC stocks for the Crocodile River catchment during the assessment period (2000-2015) indicated that a large proportion of the catchment (>99%) was stable (**Error! Reference source not found.**), and very few pixels were found to be degraded.

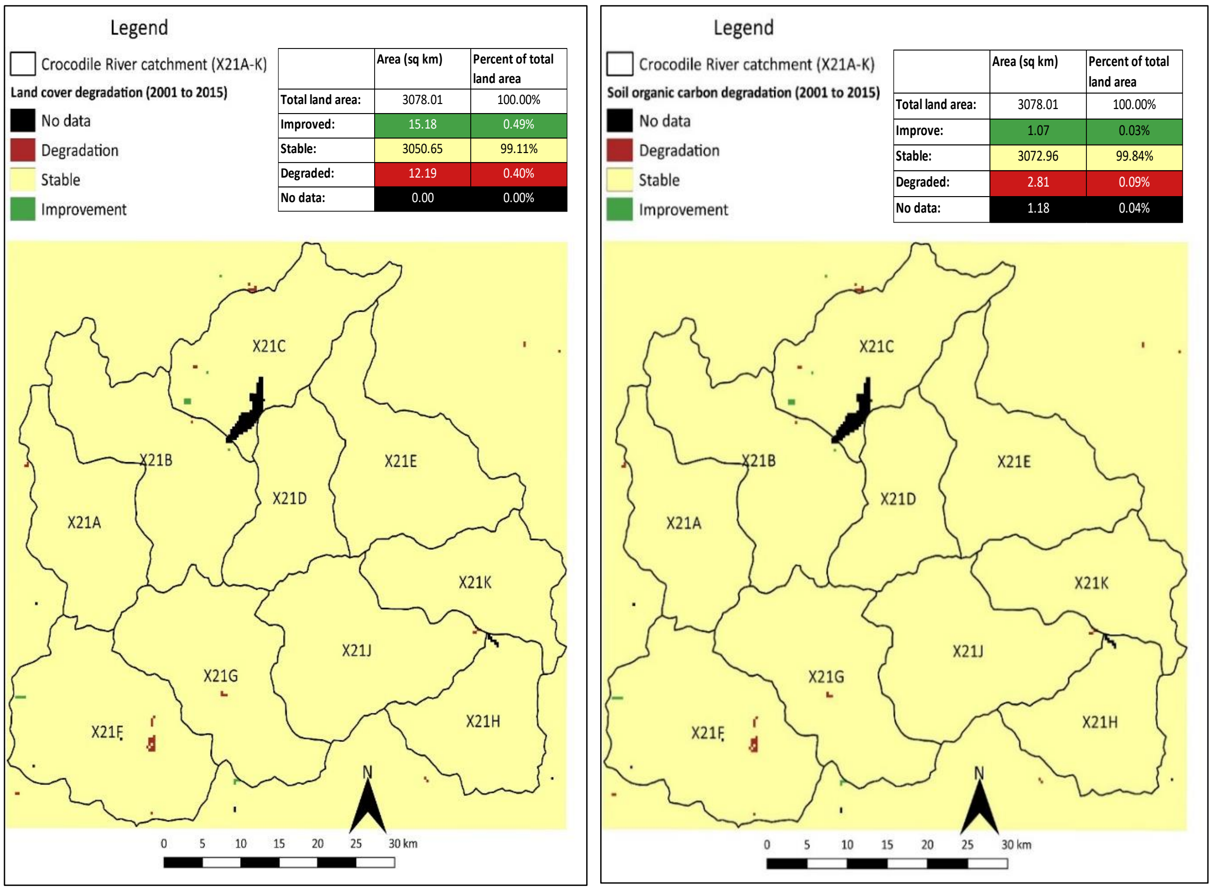


Figure 3-44 (a) Left: Land cover change for Upper Crocodile catchment between 2001 and 2015, and (b) Right: Soil organic carbon change. The Tables show a summary of change.

3.3.5.4 SDG 15.3.1: Proportion of land degraded in Crocodile River catchment

The spatial patterns of the results for climate corrected SDG 15.3.1 degradation for the upper Crocodile River catchment (Figure 3-45) indicates that most pixels (65%) in the catchment were in a stable state, and a moderately high estimate (34% degraded area) of human-induced land degradation was detected, primarily due to a shift from croplands to tree-covered areas (possibly invasive plants) and due to increase in artificial areas (from tree-covered and grasslands) (details not shown).

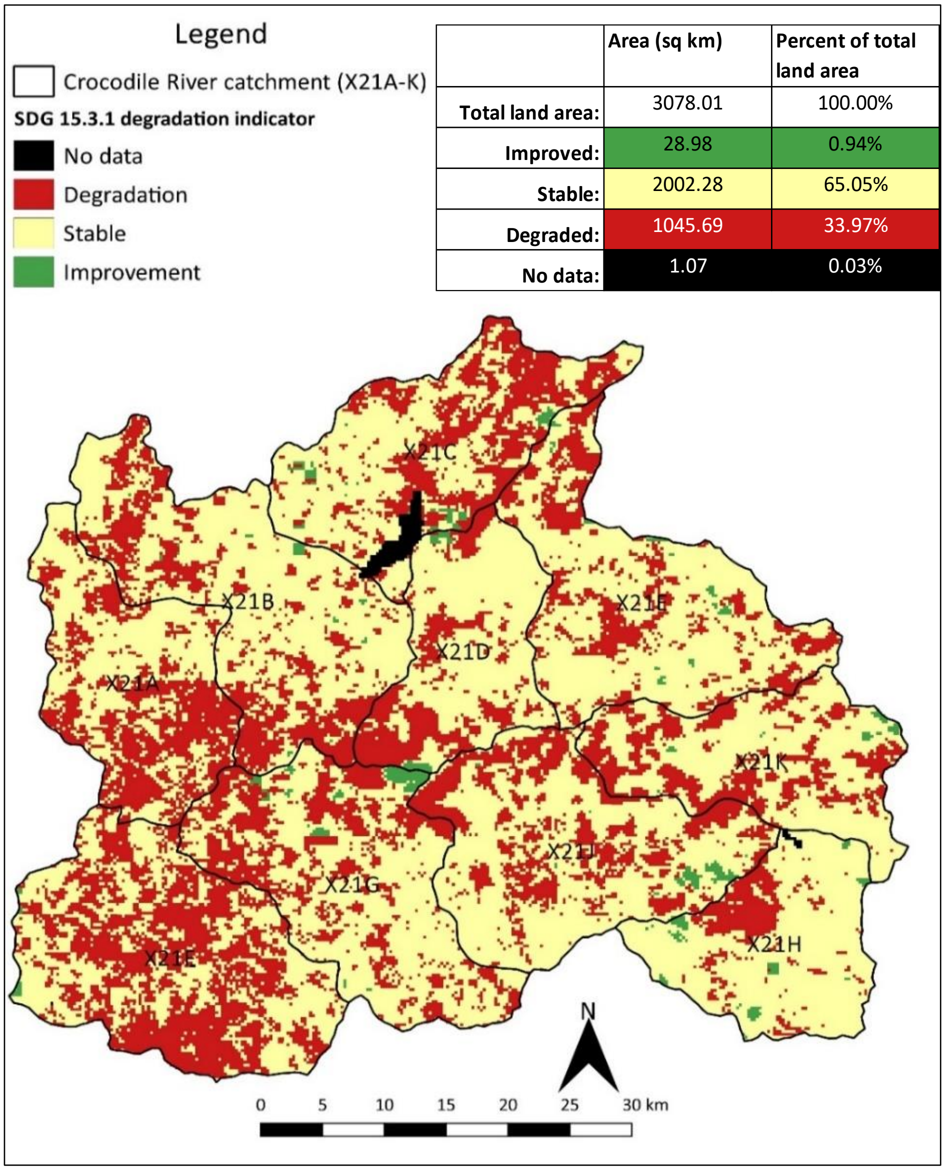


Figure 3-45 Patterns of human-induced land degradation (SDG 15.3.1 degradation indicator) in Crocodile River catchment for the assessment period covering the years 2001 to 2015

3.4 Prioritisation criteria, datasets and results for rehabilitation

3.4.1 Background

Prioritising areas for rehabilitation is essential to get the best returns in terms of improved EI and benefits to society including flow regulation ecosystem services. A method for prioritising for water resources management is Multi-Criteria Decision Analysis (MCDA), which has been applied in South Africa and elsewhere (Joubert, Stewart and Eberhard, 2003; Dollar et al., 2010; Forsyth et al., 2012; Favretto et al., 2016). MCDA is a framework for integrating different criteria and constraints for decision-making. Research by Forsyth et al. (2012) used a Analytic Hierarchy Process (AHP), a type of multi-criteria decision model, for prioritising high priority invader species for WfW operations in the Western Cape. The analysis by Forsyth et al. (2012) focused on prioritising quaternaries in primary catchments E, G, H, J and K using 12 spatial datasets in Fynbos, Succulent Karoo and Nama Karoo biomes. The datasets ranked criteria by determining their relative importance for alien plant control operations through stakeholder workshops. Another study in Southern Africa evaluated the delivery of ecosystem services under a diverse set of land use and management possibilities for rangelands in Botswana's southern Kgalagadi District (Favretto et al., 2016). The various land management scenarios evaluated by the study were private cattle ranching, communal livestock grazing, private game farming, and wildlife management areas. The study concluded that communal grazing provided the greatest range of (monetary and non-monetary) ecosystem services. MCDA has also been used locally for making decisions about water supply systems and water resource classification in South Africa (Jourbert, Stewart and Eberhard, 2003; Dollar et al., 2010).

3.4.2 Prioritisation methodology

The AHP method (Saaty, 1990) was used in this study to prioritise targeted EI land cover categories defined earlier (wetlands, riparian zones, grasslands and abandoned cultivation areas) for restoration to improve flow regulation in the catchment. Figure 3-46 summaries the steps and datasets involved in the calculations. There are various benefits of rehabilitating EI that have been discussed above and these include:

- flow regulation ecosystem service (important at catchment level)
- improved biodiversity (important from a national scale)
- other ecosystem services such as water provisioning and sediment retention (important for the local communities, for the catchment and for infrastructure such as dams)

- benefits identified by local communities during workshops that are stakeholder priorities.

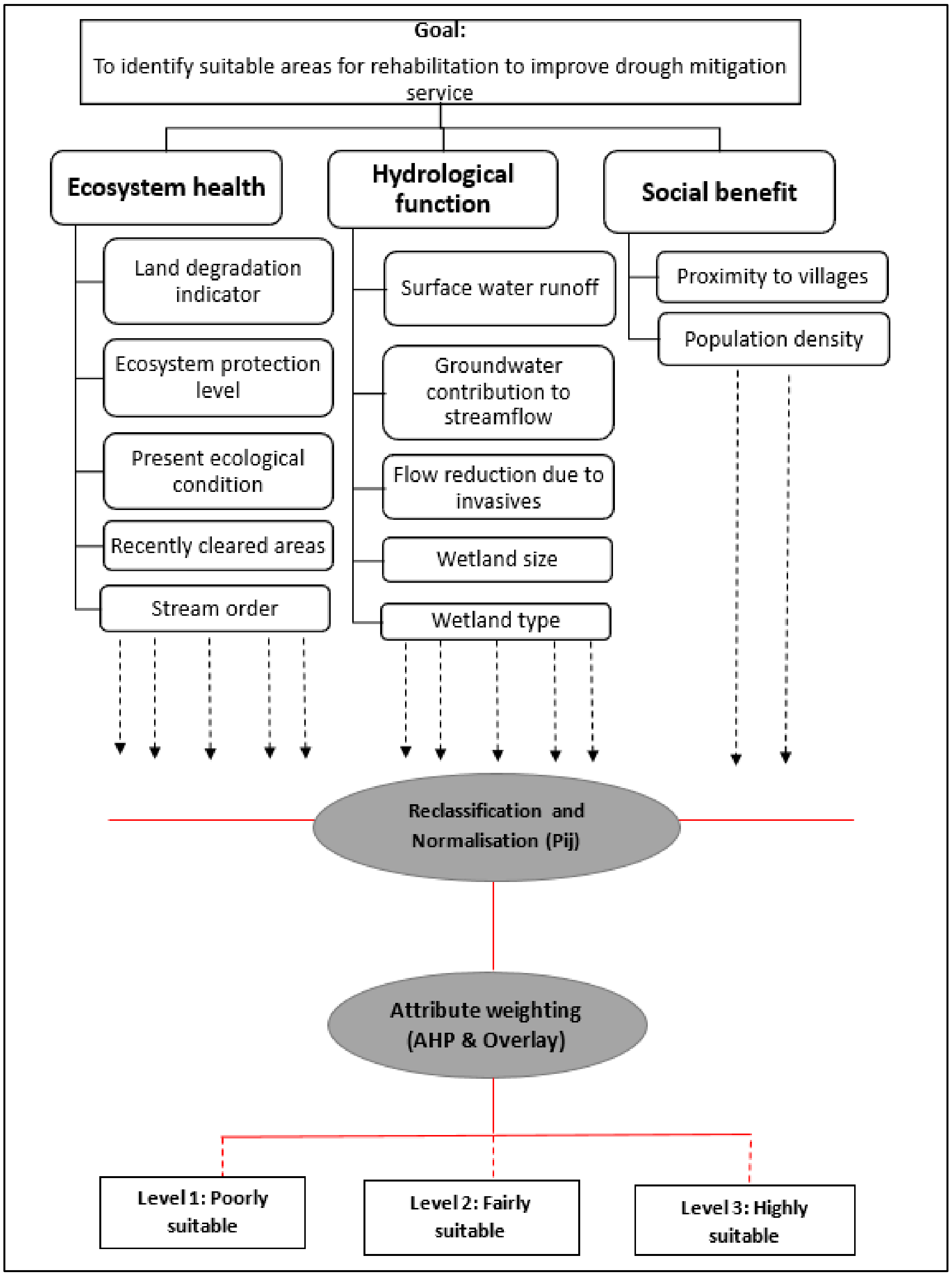


Figure 3-46 Schematic diagram showing the general steps followed for the AHP model process

The feedback from community stakeholders within the catchments was used to identify key EI resources, and the criteria used to identify important EI locations which are related to three broad benefit categories: ecosystem health, hydrological functioning and social benefit (Figure 3-46). For the Cacadu and Tsitsa catchments, the stakeholder inputs were obtained in person during the 2019 workshops (Section 3.4.3), while for the Upper Crocodile, Mr Xoxo evaluated previous

WRC and published reports to gather this information. Section 3.4.4 provides more details about the various datasets that were used for the analysis under the three main criteria of ecosystem health, hydrological function and social benefits.

3.4.3 Community feedback into prioritisation

Feedback from the community stakeholders was obtained during stakeholder workshops with five Machubeni villages and two Tsitsa catchment villages during 2019. This was used to identify key EI resources, and the criteria used to identify important EI locations. For the Upper Crocodile, Mr Xoxo evaluated previous WRC and published reports to gather relevant stakeholder information.

Community priorities for Machubeni GEF5 villages

Please refer to Appendix 1 for detailed methods employed to gather the communities' valuing of the EI land covers in Machubeni villages. Two group workshops were held in Machubeni area: group meeting 1 (WS1) for the villages on the eastern side of the case study area involving stakeholders from Platkop and Gxojeni sub-villages with 15 participants, and group meeting 2 (WS2) for the western side villages involving stakeholders from Qhoboshane, Boomplaas and Helushe sub-villages with 25 participants. Previous workshops by GEF team had identified the key resource areas that are important to the community. These resources were drawn as land cover polygons of rangelands and croplands and wetlands superimposed on Google Earth imagery of the village and projected on a screen for visual access to everyone (see Appendix 1 for the images that were presented to the workshop participants). Popular place names in the area were used as feature markers (or landmarks) for the participants to locate themselves in the maps, including schools and mountain ridges. The attendees were then asked to confirm the locations of key resource areas. After verifying the focal EI resources, participants were prompted to share their views on which resources they value the most and what criteria define how they valued the resource area. The stakeholders were asked to define the relative importance of the resources into two classes only (less important and more important). Box 3-2 presents a summary of their feedback.

Box 3-2: Conclusions about targeted EI land covers based on stakeholder opinions in Machubeni communal area

- Wetlands are important for water and fodder provision to livestock. The most important are those that can supply water all-year round.
- Rangelands are important for fodder provision. The most important are the healthiest and those that are within walking distance (i.e. less than 2 km away from the homesteads), and have healthy natural vegetation.
- Riparian zones are all valued for their ability to provide water and fodder. But when heavily eroded, riparian areas are dangerous to livestock, the elderly and children.
- Abandoned croplands are predominantly encroached by the woody *Euryops floribundus* plant, or invaded by IAPs. Secondly, since some croplands are still active, the use of cropland areas as surrogate grazing areas is not an acceptable practice.

The following presents the feedback about the important focal EI land cover types identified by the GEF5 village community. The most prioritised rangeland in Qhoboshane consists of the Southern Drakensberg Highland Grassland veld type (Figure 3-47). In Helushe and Boomplaas, the most prioritised rangeland consists of the Tsomo Grassland veld type. During the field trip, georeferenced coordinates for the springs and boreholes in the area were collected by Mr Xoxo for the GEF5 project. The vegetation that grows in the wetlands was identified as supplementary fodder especially during the dry seasons. However, other studies (including those in Tsitsa) have found these key resource areas to be subject to degradation (e.g. Cowden et al., 2014). A breakdown and detailed description of the priority EI can be found in the MSc thesis by Mr Sinetemba Xoxo (Rhodes University).

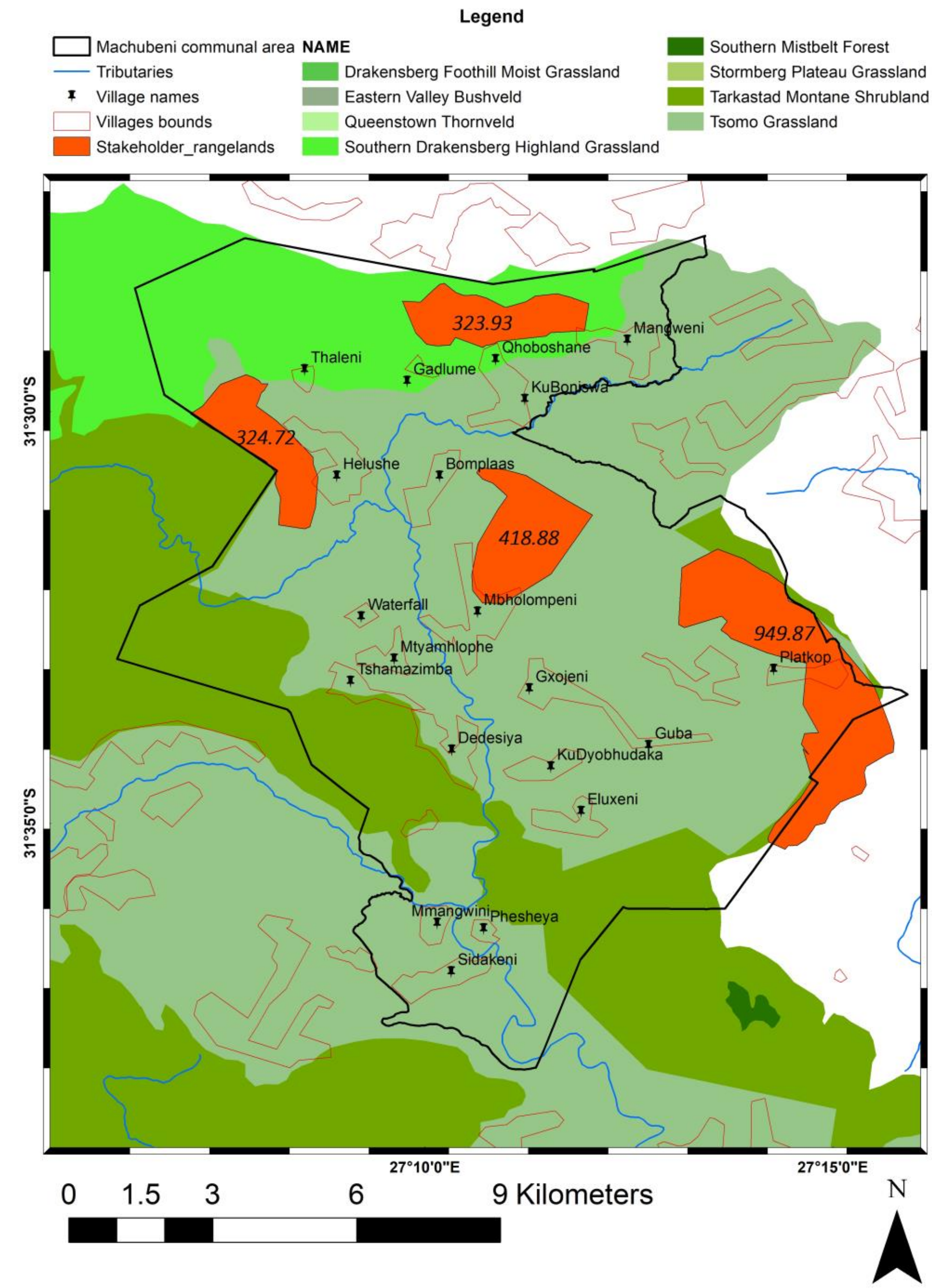


Figure 3-47 Map showing verified and priority rehabilitation grazing areas derived from stakeholder discussions in the GEF villages.

A list of proxies for how the community stakeholders decide on important resources (Table 3-5) was derived during the workshop. Wetlands and riparian areas were allocated a higher priority based on their ecosystem condition (e.g. intact or degraded), and the availability of resources (e.g. water and healthy grasses). For wetlands, the ecosystem condition was mostly based on whether a certain wetland or spring that feeds the wetland is still active and whether it remains active during the dry season, while the availability of resources was based on water and fodder supply especially during the dry periods. For the riparian areas, the ecosystem condition for the riverbanks was determined by the availability of constant water flow and grasses, and available resources were determined similar to wetland ecosystems. Rangelands were allocated a higher ranking based on ecosystem condition (e.g. degraded or not), and availability of resources (e.g. healthy sweet veld grasses) (Table 3-5). Additionally, rangelands were allocated a higher ranking based on their distance from the homesteads and the area of the resource.

Table 3-5 Four criteria list derived from stakeholder views. A tick depicts applicability of criteria to resource priority by stakeholders. The PGIS exercise excluded verification of cropland areas, and the locals decided to prioritise all the croplands. Therefore, the criteria list shows a grey fill for croplands because none of the proxies was used by the community to rank the croplands

Focal EI land cover resource	**Criteria**			
	Condition	**Available resources**	**Distance from home**	**Resource size**
Wetlands	✓	✓	Not important	Not important
Rangelands	✓	✓	✓	✓
Croplands				
Riparian areas	✓	✓	Not important	Not important

Community priorities for Tsitsa catchment communities

Please refer to Appendix 2 for the detailed method used to gather community prioritisation information. Participatory mapping was conducted in two selected villages in the upper catchment of Tsitsa (T35A; Figure 3-48). The Tsitsa Project at Rhodes University selected Sigoga and Ntatyaneni villages because of the strong existing research relationship established by ongoing catchment rehabilitation work. A process similar to the one used in Machubeni was followed with the use of Direct-to-Digital participatory GIS. The community group at the workshops agreed upon the criteria for prioritising the ecological infrastructure based on their availability throughout the year, distance from the village, availability of grazing areas for livestock (Table 3-6). The community mapped the priority areas and these were captured using Google Earth (Figure 3-49 and Figure).

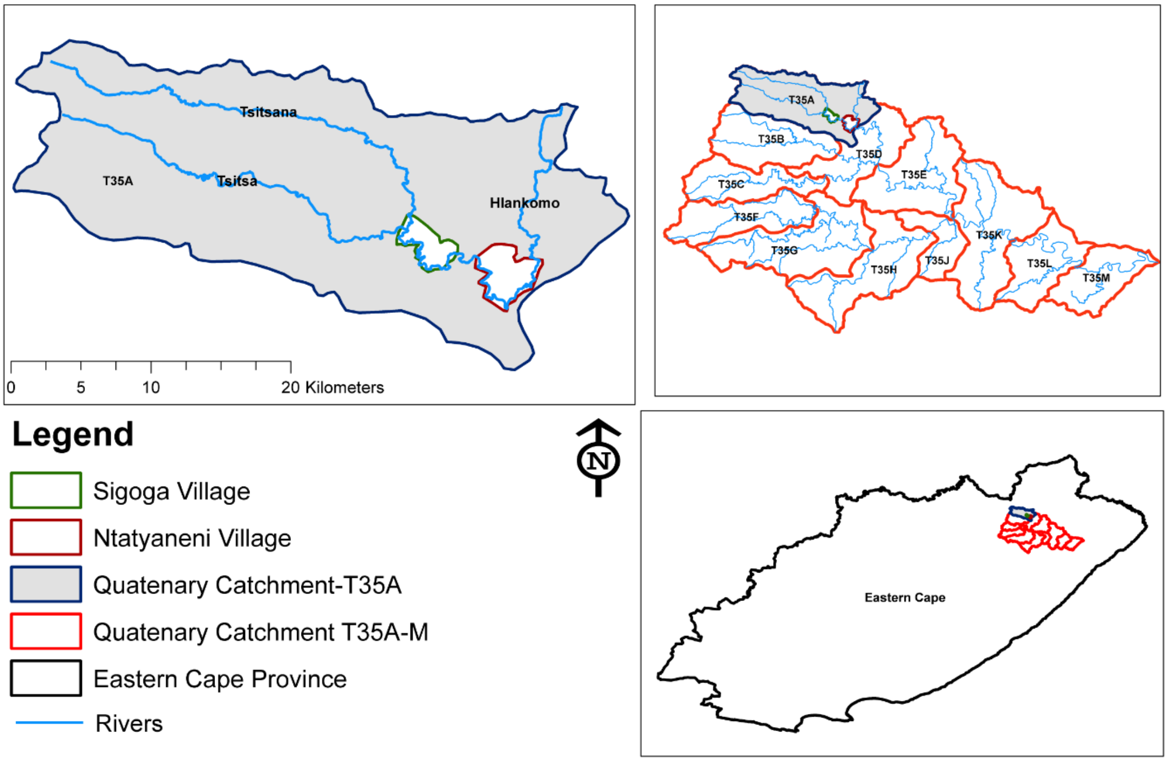


Figure 3-48 Location of Sigoga and Ntatyaneni villages in T35A catchment

Table 3-6 Prioritisation criteria for each key natural resource as identified by the community group during the workshop

Focal EI land cover resource	**Criteria for prioritisation**
Springs/Wetland	Prioritised springs are those with good water quality and communities use them as a source of drinking water. Springs that flow throughout the year or have a high-water yield. Springs that are accessible and are within a reasonable distance to homesteads. Wetlands with water and good vegetation around for livestock grazing.
Abandoned cultivated lands	Important abandoned croplands are those with no or low degradation (i.e. abandoned croplands with recovered vegetation) and good grass cover for livestock grazing.
Rangelands	Rangeland priority was based on grass cover present in the field and those within a close distance from the homesteads and water sources.

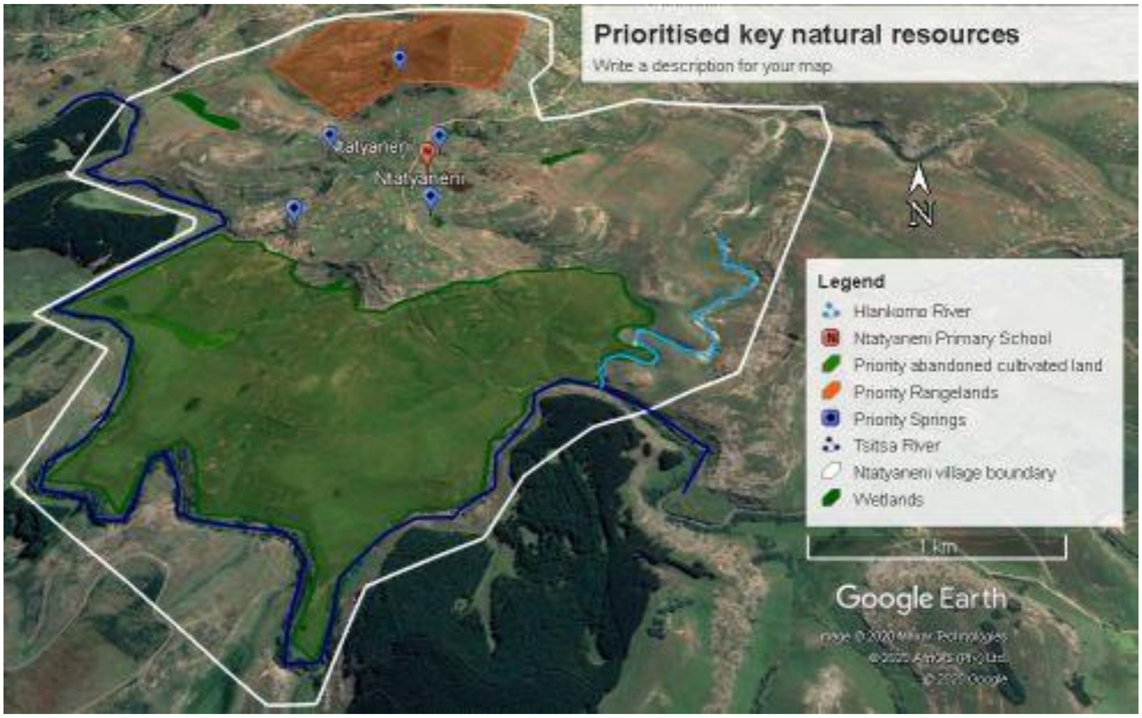


Figure 3-49 Google Earth image showing prioritised key natural resources at Ntatyaneni village

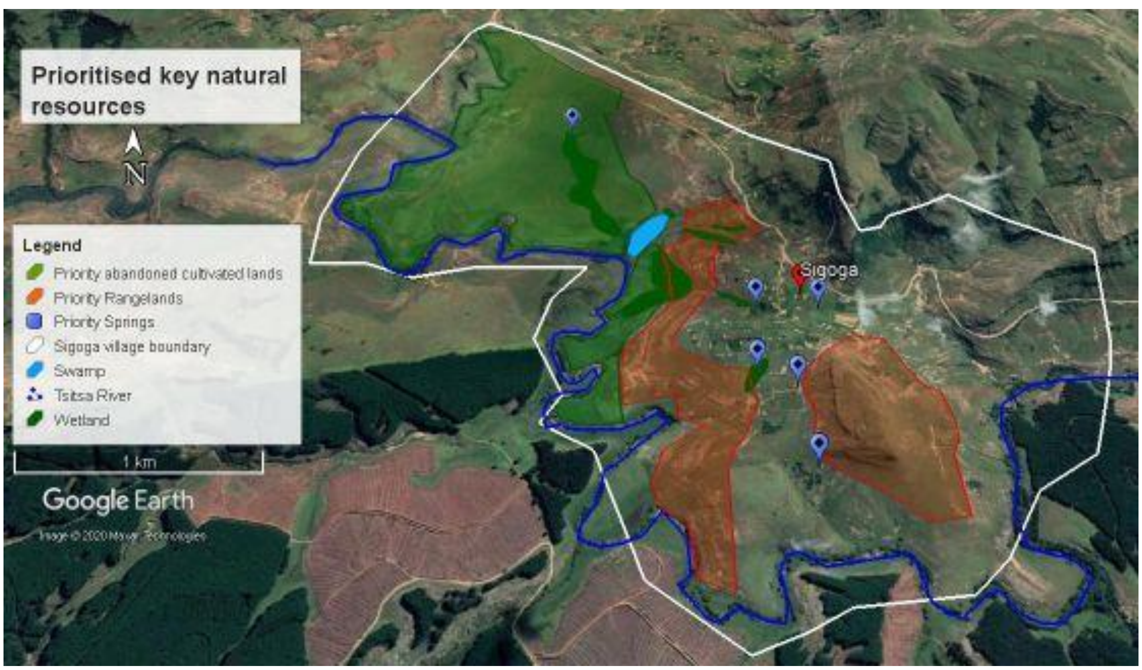


Figure 3-50 Google Earth image showing prioritised key natural resources at Sigoga village

Community priorities for Crocodile River catchment

A summary of the themes important to the stakeholders in the Crocodile River catchment were derived from a review of the following peer-reviewed literature and reports (including grey literature on IUCMA website):

Rogers, K., 2010. Inkomati Catchment Management Strategy Visioning Exercise. Crocodile River Sub-catchment. Report available on IUCMA (https://www.iucma.co.za/reports-and-documents/documents/, accessed April 2020).

Rogers, K., 2010. Inkomati Catchment Management Strategy Visioning Exercise. Komati River Sub-catchment. Report available on IUCMA (https://www.iucma.co.za/reports-and-documents/documents/, accessed April 2020).

Department of Water Affairs, 2013. Ecostatus of the Crocodile River Catchment, Inkomati River System. Edited by Francois Roux and Marcus Selepe. DOI: 10.13140/RG.2.1.1157.3208.

Kingsford, R.T., Biggs, H.C. and Pollard, S.R., 2011. Strategic Adaptive Management in freshwater protected areas and their rivers. Biological Conservation, 144, pp.1194-1203.

Palmer, C. G., and V. Munnik. 2018. Practising adaptive IWRM. Integrated water resources management (IWRM) in South Africa: towards practising a new paradigm. Report No. K5/2248. Water Research Commission, Pretoria, South Africa. ISBN: 978-1-4312-0983-5.

Pollard, S., du Toit, D., Pollard, S. and du Toit, D., 2011. Towards Adaptive Integrated Water Resources Management in southern Africa: The role of self-organisation and multi-scale feedbacks for learning and responsiveness in the Letaba and Crocodile Catchments. Water Resources Management, 25, pp.4019-4035.

Rogers, K.H. and Luton, R., 2016. Building an Adaptive and Stakeholder-Centred Catchment Management Agency in the Inkomati/Usuthu River Catchment. Pretoria, South Africa.

The stakeholder in the Crocodile catchment have indicated that insufficient protection of terrestrial and inland aquatic ecosystems has exposed the catchment to reduced streamflow, and dry season flows contribute to the deteriorating quality of freshwater. The identified drivers of streamflow reduction included IAP naturalisation, including commercial plantations, wetland destruction and poor landscape planning. The stakeholders indicated that anomalous flows threaten freshwater resources sustainability. This is primarily due to invaded grasslands, riparian zones, and expansion in plantation areas over the years. Lack of ecosystem protection was identified as a threat to the pristine wetlands and the services provided by the wetlands. Invasive plants and other exotic plants have been noted to outcompete native vegetation in riparian zones. Unregulated rural and urban development is seen as a threat to freshwater resources such as wetlands.

3.4.4 AHP input datasets

The AHP analysis utilised various spatial datasets and community priorities as criteria for prioritising the four focal EI land covers in each catchment. The spatial datasets included the land degradation assessment along with some of the spatial EI maps presented above as inputs into the catchment level evaluation for rehabilitation prioritisation of the focal EI land cover types. The AHP inputs are shown in Table 3-7 and details about these datasets are presented below.

3.4.4.1 Attributes relating to the ecosystem health status criterion

I. **Land degradation status (SDG 15.3.1):** The proportion of degraded land is an essential indicator of the location and extent of degradation at the focal catchments (Section 3.3). The SDG 15.3.1 indicator attribute encapsulates the catchment health status (with climate extremes removed). The land degradation status is useful for weighing the capacity of vegetation and land cover in catchments to regulate runoff (Le Maitre, Kotzee and O'Farrell, 2014).

II. **Ecosystem protection level (EPL):** The EPL dataset takes into account ecosystem connectivity and monitors the extent of ecosystem protection across landscapes (Skowno et al., 2019b). The EPL legend categorises native biomass into four categories namely, well-protected (i.e. 100% protection of the ecosystem), moderately protected (i.e. 50-100% protection), poorly protected (i.e. 5-50% protection) and not protected (i.e. <5% protection). Restoration literature (Stavi and Lal, 2015; Mander et al., 2017; Hoffman et al., 2018) indicates that protected ecosystems are less vulnerable to further degradation. Over 65% of terrestrial ecosystems in the Cacadu catchment are not protected, and the remainder of ecosystems (35.5%) are under some protection.

III. **Recently cleared areas:** The focal catchments fall within the Grassland Biome and are often threatened by woody encroachment and IAP naturalisation (Luvuno et al., 2018; Van Wilgen et al., 2008). Therefore, the transformation from tree-covered areas (presumed to be IAPs) to other EI categories was viewed as a form of restoration activity in this study. The recently cleared areas attribute is based on the 300 m European Space Agency global dataset that covers the years 2000-2018 (ESA, 2018, Section 3.3). Following the feedback obtained from the WRC Reference Group memmbers, recently cleared areas were prioritised to ensure that the effectiveness of clearing interventions is achieved through ongoing treatments and maintenance.

Table 3-7 Summary of input datasets under the three main criteria that were used to derive the attributes for the prioritisation assessment

Main criteria	Attributes (spatial datasets)	Description	Resolution
Ecosystem health status	Land degradation indicator (Conservation International, 2018)	Raster layer showing degradation states for focal EI	250 m
	2018 Ecosystem protection level (SANBI, 2018)	Raster file showing protection level of terrestrial ecosystems excluding aquatic ecosystems	30 m
	Recently cleared areas (EuroSpace Agency, 2017)	Raster layer showing the transformation of tree-covered areas area to other land cover classes covering the period 1990-2018.	300 m
	Stream order (DWS, 2006)	Vector layer with 1-7 stream order levels as line features	1: 500 000
	Present ecological status (van Deventer et al., 2019a)	NBA layer for inland aquatic ecological conditions	1: 500 000
Hydrologic functionality	Estimated flow reduction by IAPs (Le Maitre et al., 2016)	Raster layer of % annual reduction factor by IAPs	250 m
	Groundwater recharge (Le Maitre et al., 2018a)	Raster map showing annual average aquifer recharge	1 km
	Surface water runoff (Le Maitre et al., 2018a)	Raster map showing water source areas by mean annual runoff	1 arc minute
	National Wetlands Map (van Deventer et al., 2019a)	NBA vector layer of ecological condition, hydro-geomorphic type and protection level. Wetland size is also included as area (ha)	1: 5 000
Social benefit	EI distance from the villages (StatsSA, 2011)	Proximity derived from RSA sub-areas vector layer	1:250 000
	Population density (StatsSA, 2011)	Vector layer showing population density per km^2	1: 250 000

IV. **Present ecological status (PES):** Riverine and wetland conditions are presented using a set of the freshwater PES of categories that were designed by the Department of Water Affairs used for describing the ecological condition of rivers, which is similar to wetlands (Macfarlane et al., 2009). The assessment of the PES considers a range of factors, including physio-chemical conditions, flow, and habitat quality (van Deventer et al., 2019a). This attribute was derived from the 2018 NBA inland aquatic database, which presents the river PES and wetland PES with a range from A (natural) through to F (severe modification).

V. **Stream order:** The choice of including stream order in prioritising riparian areas is due to the assumption that vegetation structure influences streamflow, with non-native plants causing the most reductions in streamflow (Le Maitre et al., 1996; Le Maitre, Versfeld and Chapman, 2000; Le Maitre, Gush and Dzikiti, 2015). Therefore, management interventions such as the Working for Water programme give a higher priority to headwaters to prevent further reinvasion downstream as per the provision of the Mountain Catchment Areas Act (Act 63 of 1970) (Turpie, Marais and Blignaut, 2008).

3.4.4.2 Attributes relating to the hydrological function criterion

I. **Groundwater contribution to streamflow**: Precipitation is the primary source of catchment water recharge. However, during the dry season and drought periods, precipitation declines, and the groundwater becomes the primary source of stream recharge through baseflow (Smakhtin, 2001; Stoelzle et al., 2014). Therefore, high groundwater recharge areas are hotspots for reliable water supply. This study uses mean annual groundwater recharge as a proxy for the groundwater availability and contribution to streamflow through baseflow. Recharge data were taken from the second national Groundwater Recharge Assessment hosted in the South African Water Resources database (Bailey and Pitman, 2016).

II. **Surface water runoff (MAR)**: The surface water runoff attribute is an essential indicator for the streamflow regulation function of catchments (Brauman et al., 2007; Le Maitre, Kotzee and O'Farrell, 2014). The attribute also relates to the strategic water source areas, which are high water production areas with an average annual runoff that exceeds 135 mm (Le Maitre et al., 2018a). Strategic water source areas occupy a small surface area (8%) of South Africa's total area but contribute to over 50% of water supply, making them important freshwater source areas. Therefore, the restoration of the EI categories within the higher-yielding area is essential for water regulation within the catchment and consequently, drought mitigation (Nel et al., 2011a). High runoff areas were given a higher rating for AHP model scoring.

III. **The estimated flow reduction due to IAP (MAR reduction):** Presence of IAPs constitutes a significant threat to freshwater in South African catchments (Le Maitre et al., 2019; Turpie, Marais and Blignaut, 2008; Le Maitre, Gush and Dzikiti, 2015). Therefore, we have included the estimated flow reduction estimated by Le Maitre et al. (2016) in the analysis. The estimated proportion of flow reduction by IAP ranges from 0% to 34% reduction nationwide at 250 m spatial resolution.

IV. **Wetland size**: Inclusion of wetland size as an attribute is based on the assumption that larger wetlands generally have a higher potential of contributing to surface water flows (Rebelo et al., 2015; Kotze, Tererai and Grundling, 2019). However, it must be noted that some smaller wetlands are key repositories of biodiversity. Additionally, the next attribute (wetland type) incorporates the hydrogeomorphic types of wetlands, which have been found to assist with flow regulation, into the prioritisation. Wetland size was derived from the fifth national wetland assessment dataset (van Deventer et al., 2019a), and larger wetlands were given a higher score for their potential role in hydrological flow regulation.

V. **Wetland type:** The wetland geomorphic type is an indicator of water movement through a wetland (Macfarlane et al., 2009). The NWM5 dataset provides wetland hydro-geomorphic units at a quaternary catchment scale, and they are classified into seven categories (van Deventer et al., 2020, 2018). Kotze et al. (2009) noted that channelled seepage and unchannelled valley-bottom wetlands are most likely to contribute to streamflow regulation. All wetland types, however, play an essential role for flood attenuation (Kotze et al., 2009). Valley-bottom and seepage wetland types were given a higher rating for their significant contribution to streamflow regulation, while the low gradient wetland types were given a lower rating.

3.4.4.3 Attributes relating to the social benefit criterion

I. **Proximity from homesteads**: The primary goal of restoration is to increase the wellbeing of the social-ecological systems through increasing ecosystem resilience (South African National Biodiversity Institute, 2014; Biggs et al., 2012; Cohen-Shacham et al., 2016). The proximity to homesteads and to rivers links to feedback derived from community stakeholder discussions. We derived buffer zones of 2 km around the village/farm area using the *Multiple Ring Buffer* tool in the ArcGIS platform. This tool in ArcGIS uses the Euclidian Distance to compute buffer zones.

II. **Population density:** Traditional communities primarily rely on natural resources for their livelihoods; therefore, areas providing ecosystem services are crucial in rural landscapes (Elbakidze et al., 2018; Sigwela et al., 2017). The population density attribute was selected as a quantitative indicator for social benefit. The population density indicator wass derived using population per sub-area (i.e. township, village or farm) over the total surface area of the sub-area using the 2011 census dataset (StatsSA, 2011).

3.4.5 AHP prioritisation results

The results are presented at catchment scale without inclusion of social benefit criterion (i.e. with only ecosystem health and hydrological functioning criteria) and secondly, with social benefit criterion included (i.e. all three criteria included and thus focus on EI areas within 2 km of villages). Thus the total area for the latter prioritisation can be smaller than the results where social benefit criterion was not included. The priority overall ranking results are presented as follows: 1-2 = low / poor suitability, 3 = moderate / fair suitability, 4-5 = high suitability. Note that the prioritisation results for abandoned croplands with social benefits is different between the catchments because of different stakeholder input. In Cacadu catchment, all abandoned croplands are considered to be equally important for rehabilitation from a social benefit point of view because the Machubeni stakeholders indicated that they would like to use all of them cropping. Thus, prioritising by distance for social benefit was not conducted in Cacadu. This justification was also used in Crocodile catchment. However, the Tsitsa stakeholders noted that abandoned croplands that had converted to grasslands should be rehabilitated as they prefer to use these as alternative grazing fields. Other grasslands had deep gullies and were not used by the community.

3.4.5.1 Prioritisation results for the Cacadu River catchment

The prioritised areas to improve drought mitigation in the Cacadu catchment without social benefit attributes (Figure 3-51 to 3-54, left figures) follows the hydrological functionality criterion. The prioritised wetlands in the Cacadu catchment are located in sub-basins S10A-C, S10E-F, S10E and S10H. None of the 33 wetlands that were prioritised by community stakeholders in the Machubeni were identified as priority by the AHP model. The highly prioritised riparian margins were second to fourth order riparian zones in the middle sub-basins and the lowest sub-basin. In terms of old croplands, the whole catchment was highly prioritised except for the abandoned croplands in the S10A sub-basin. The most suitable grassland areas to meet the AHP goal coincided with the most suitable riparian margins in the Cacadu catchment.

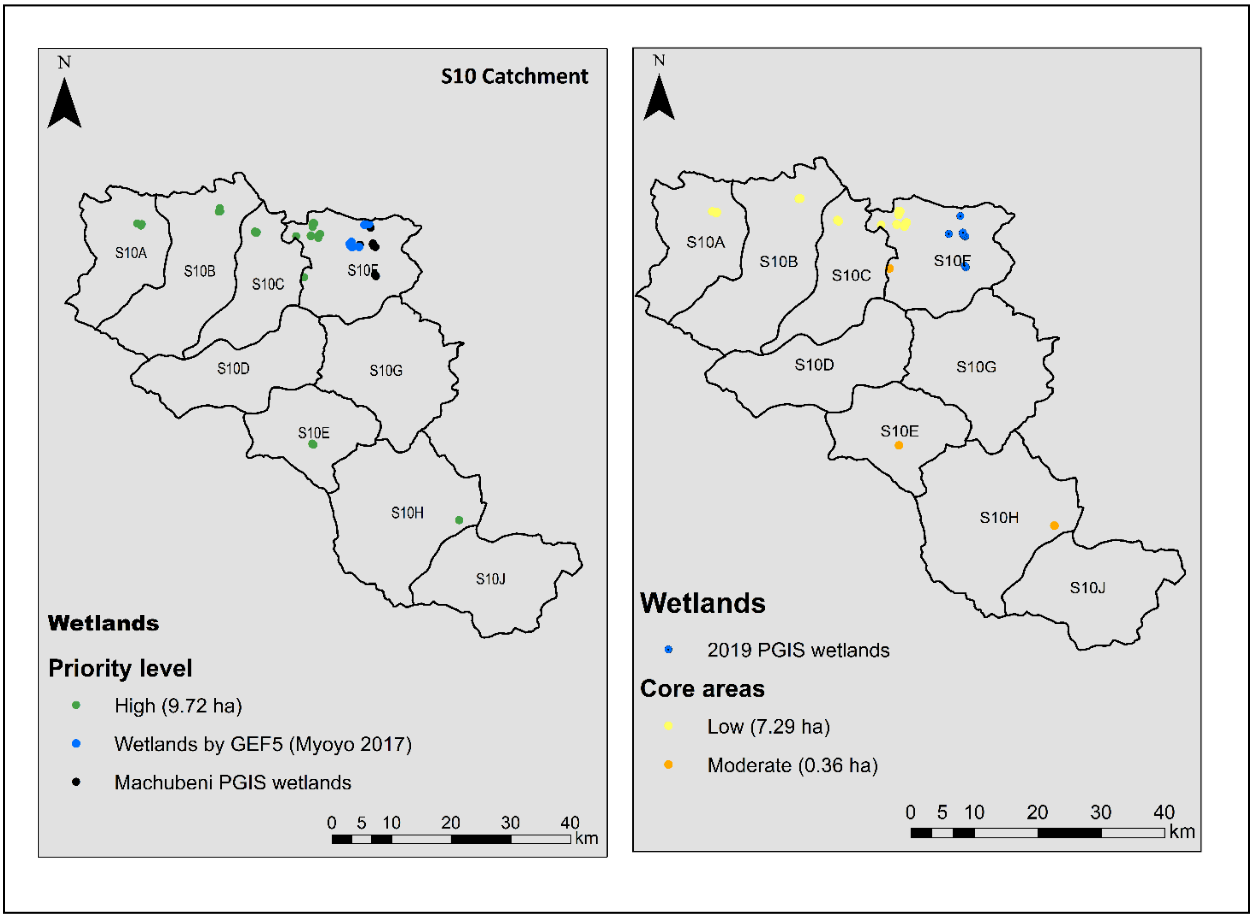


Figure 3-51 AHP model results for priority areas for wetland restoration in the Cacadu catchment without (**left**) and with (**right**) inclusion of social benefit criterion. The priority overall ranking results are: 1-2 = low / poor suitability, 3 = moderate / fair suitability, 4-5 = high suitability

The results for prioritising catchment restoration with attributes associated to social benefit included is shown in Figure 3-54 to 3-54 (right figures). The moderate and high prioritised EI areas in the Cacadu catchment formed a network in the middle to lower catchment when taking into account the local livelihoods, except for wetlands. Most of the rangelands that were prioritised by the community stakeholders in the S10F sub-basin fell within the poorly to highly suitable restoration levels.

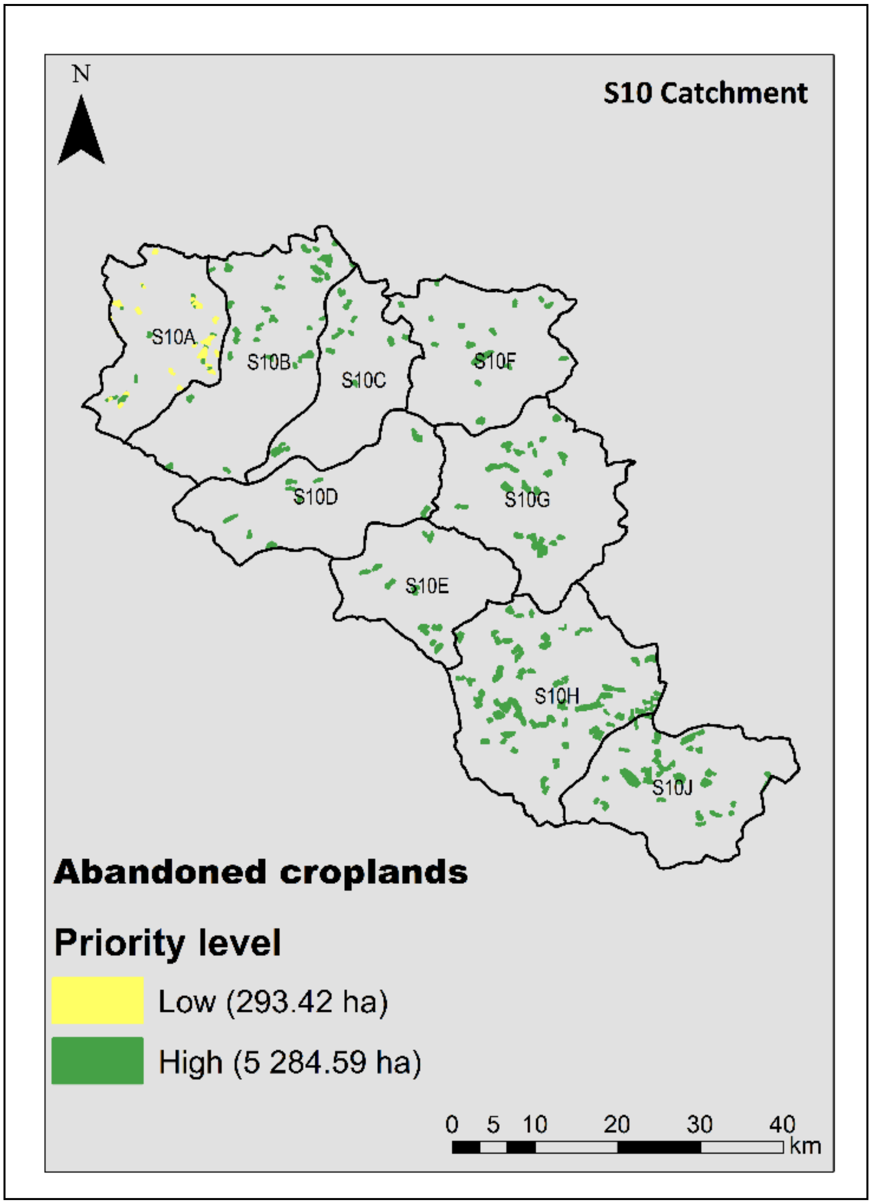


Figure 3-52 AHP model results for priority areas for abandoned cropland restoration in the Cacadu catchment. The results are the same without and with inclusion of social benefit criterion since all croplands are considered important for livelihoods of communities and distance from village is not an important attribute. The priority overall ranking results are: 1-2 = low / poor suitability, 3 = moderate / fair suitability, 4-5 = high suitability

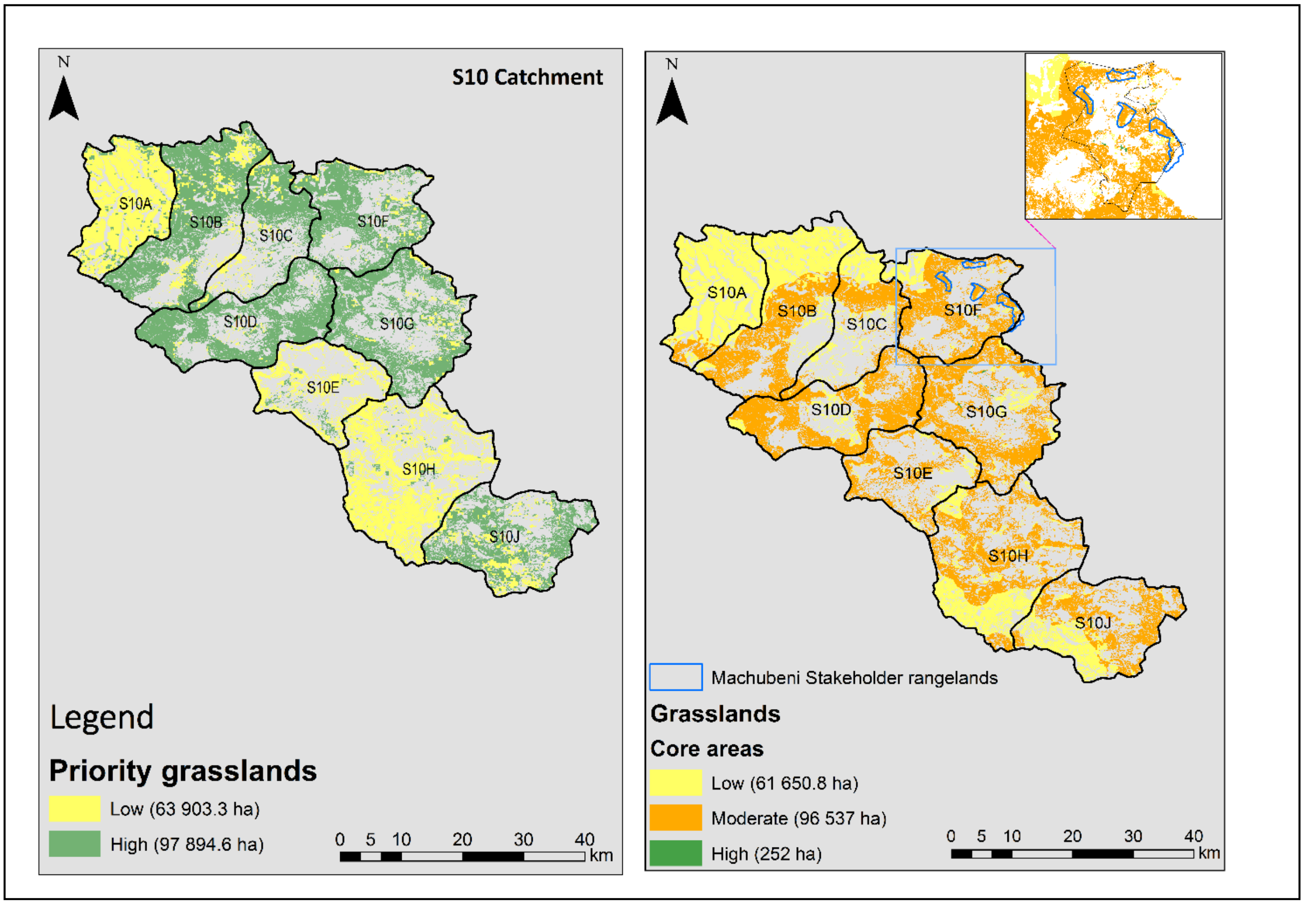


Figure 3-53 AHP model results for priority areas for grassland restoration in the Cacadu catchment without (**left**) and with (**right**) inclusion of social benefit criterion (with the inset showing the Machubeni area details). The priority overall ranking results are: 1-2 = low / poor suitability, 3 = moderate / fair suitability, 4-5 = high suitability

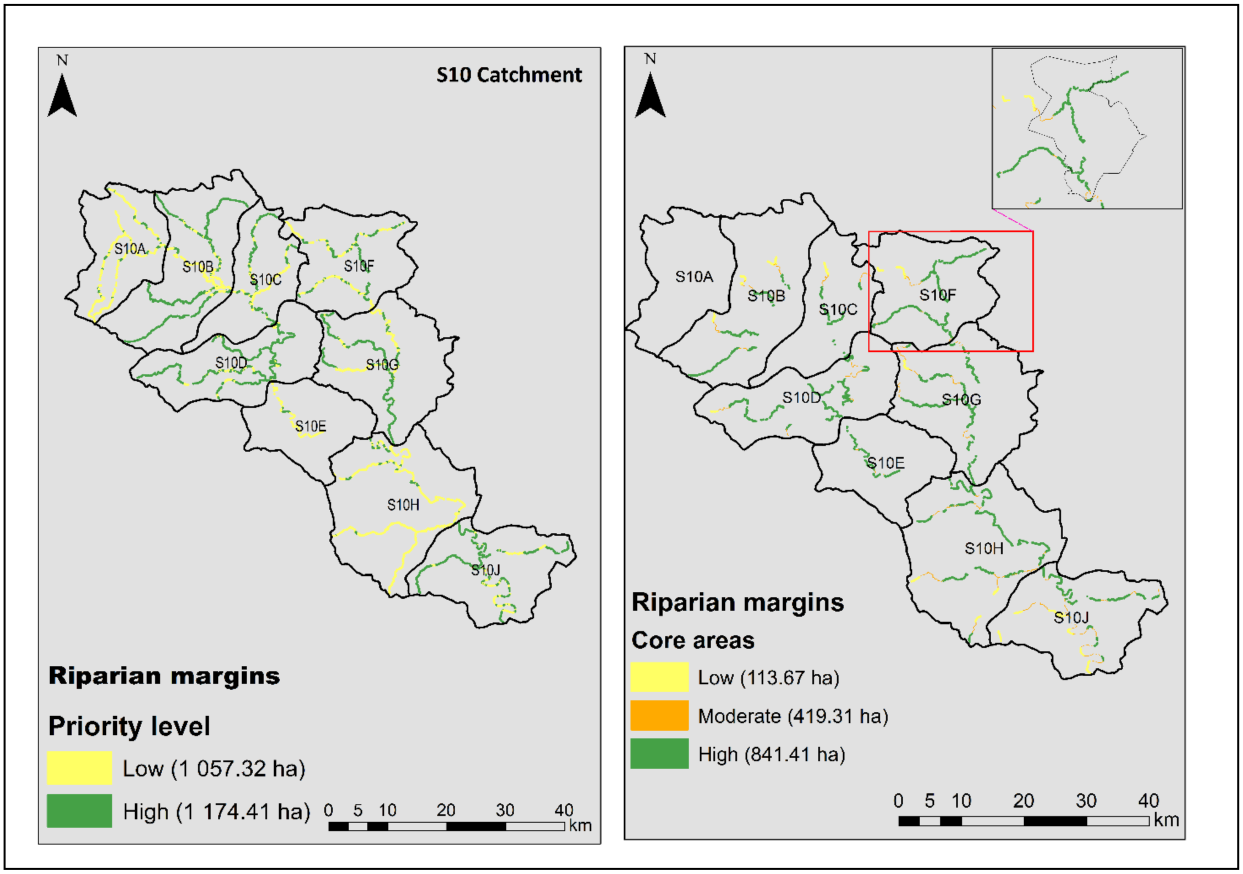


Figure 3-54 AHP model results for priority areas for riparian margins restoration in the Cacadu catchment without (**left**) and with (**right**) inclusion of social benefit criterion (with the inset showing the Machubeni area details). The priority overall ranking results are: 1-2 = low / poor suitability, 3 = moderate / fair suitability, 4-5 = high suitability

3.4.5.2 Prioritisation results for the Tsitsa River catchment

The study identified 17,703 ha of wetlands suitable for restoration with about 88% (15,720 ha) as moderately suitable, and about 11% (1,981 ha) as highly suitable for restoration. The prioritization results for wetlands with and without social benefits are very similar (Figure 3-55).

Results for abandoned cultivated fields showed about 13,608 ha as suitable areas for restoration with over 95% of the fields identified as a high priority for restoration (Figure 3-56). The result pattern was similar with social benefits with 93% of the areas close to villages (total 11,754 ha) was highly suitable and 7% was moderately suitable.

The AHP results for restoration of grasslands in T35 catchments indicated 78% (184,647 ha) of moderately suitable restoration areas, and only 21% (50, 416 ha) of grasslands as highly suitable (Figure 3-57). In terms of areas within 2 km reach of villages, the area for restoration in the catchment was reduced to 122,285 km of which 79% was moderately suitable and 16% highly suitable and 6% of low suitability for restoration.

About 3,791 ha of the riparian zones in the catchment were identified as suitable restoration areas and approximately 56% (2,135 ha) of this area was highly suitable while 44% (1,653 ha) was moderately suitable for restoration (Figure 3-58). With the inclusion of social benefits, the total area for restoration was lower (2,202 ha) with 54% as moderately suitable and 45% as highly suitable.

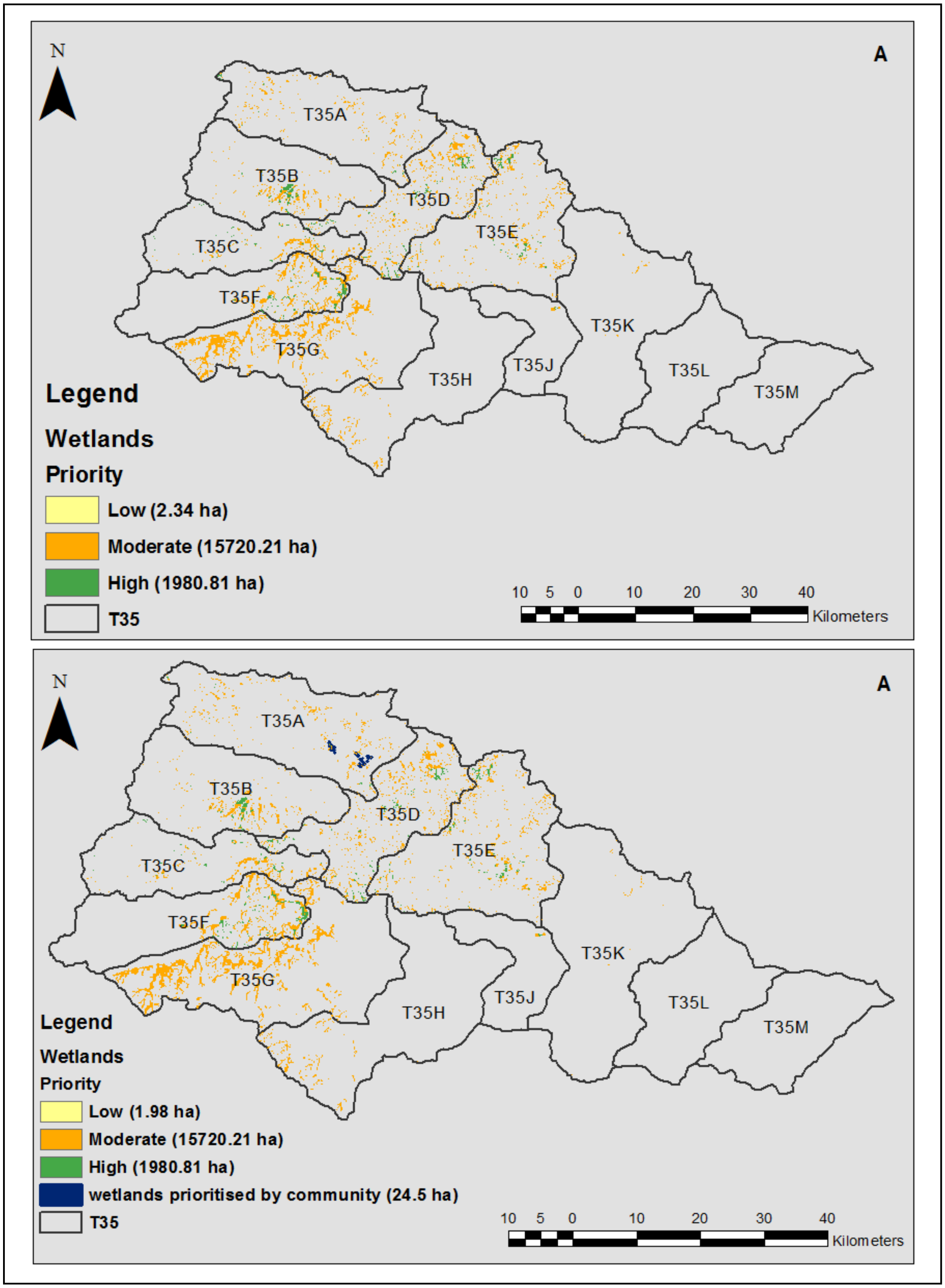


Figure 3-55 AHP model results for priority areas for wetland restoration in the Tsitsa catchment without (**top**) and with (**bottom**) inclusion of social benefit criterion. The priority overall ranking results are: 1-2 = low / poor suitability, 3 = moderate / fair suitability, 4-5 = high suitability

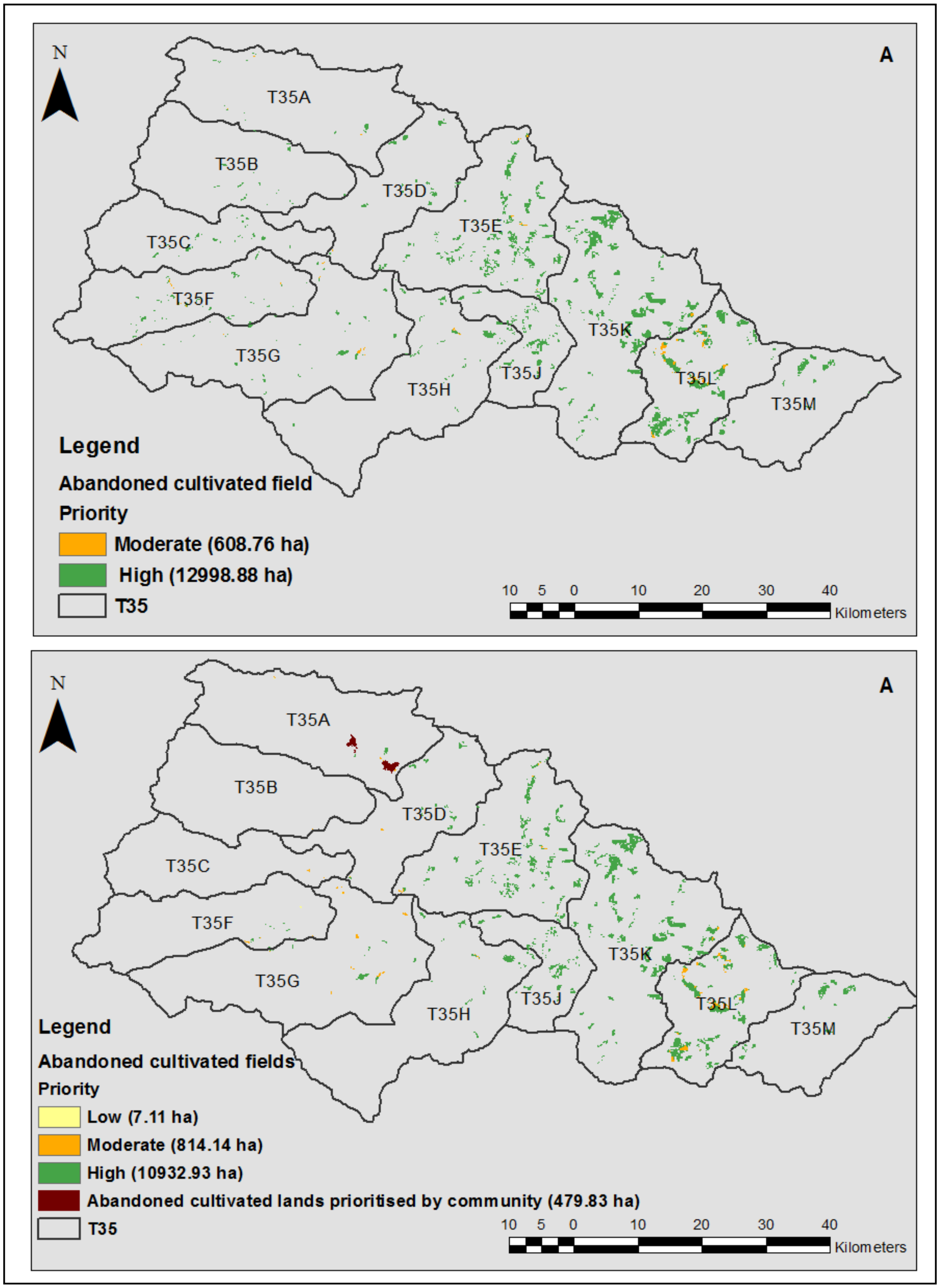


Figure 3-56 AHP model results for priority areas for abandoned cropland restoration in the Tsitsa catchment without (**top**) and with (**bottom**) inclusion. The priority overall ranking results are: 1-2 = low / poor suitability, 3 = moderate / fair suitability, 4-5 = high suitability

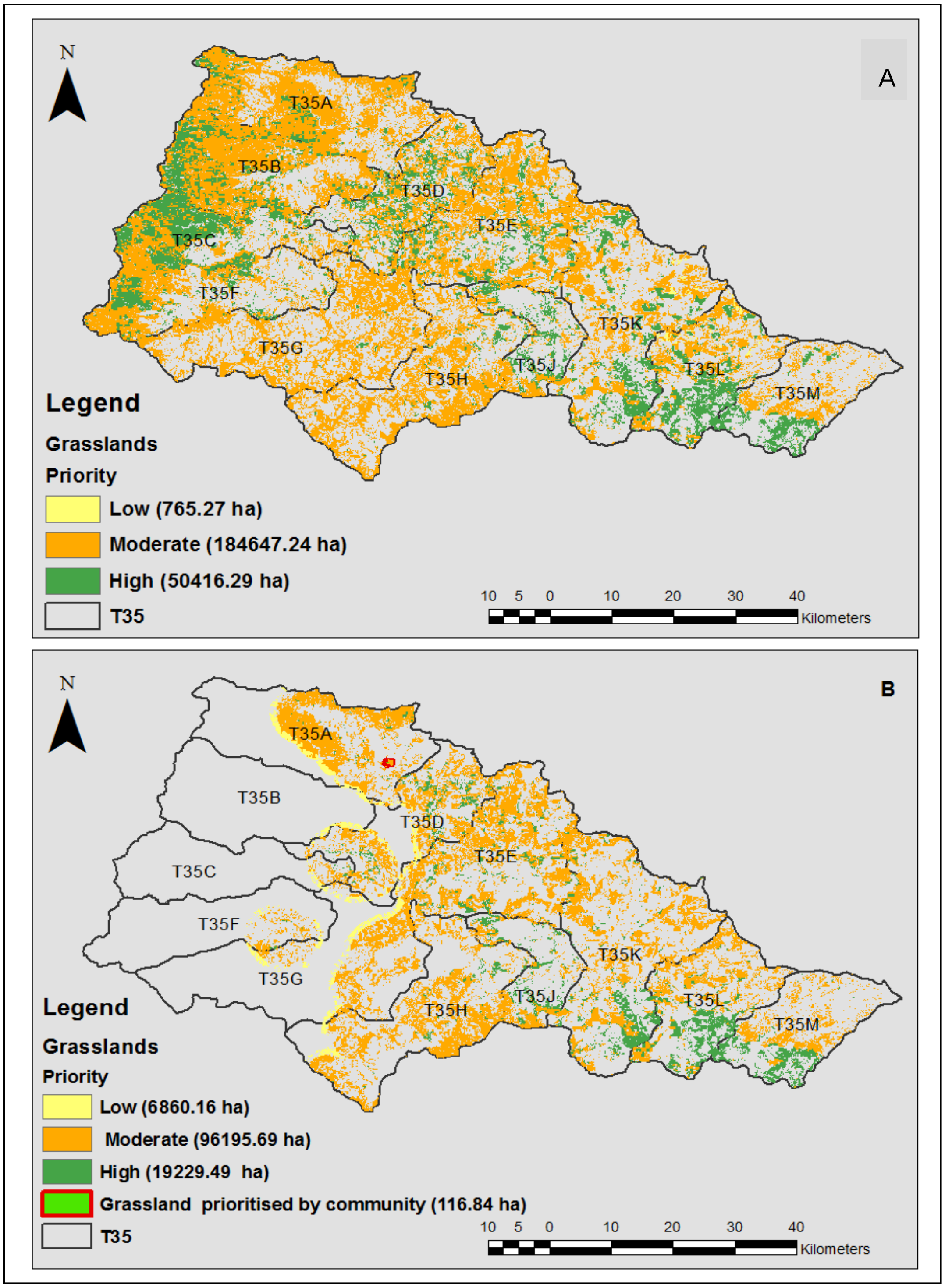


Figure 3-57 AHP model results for priority areas for grassland restoration in the Tsitsa catchment without (**top**) and with (**bottom**) inclusion of social benefit criterion. The priority overall ranking results are: 1-2 = low / poor suitability, 3 = moderate / fair suitability, 4-5 = high suitability

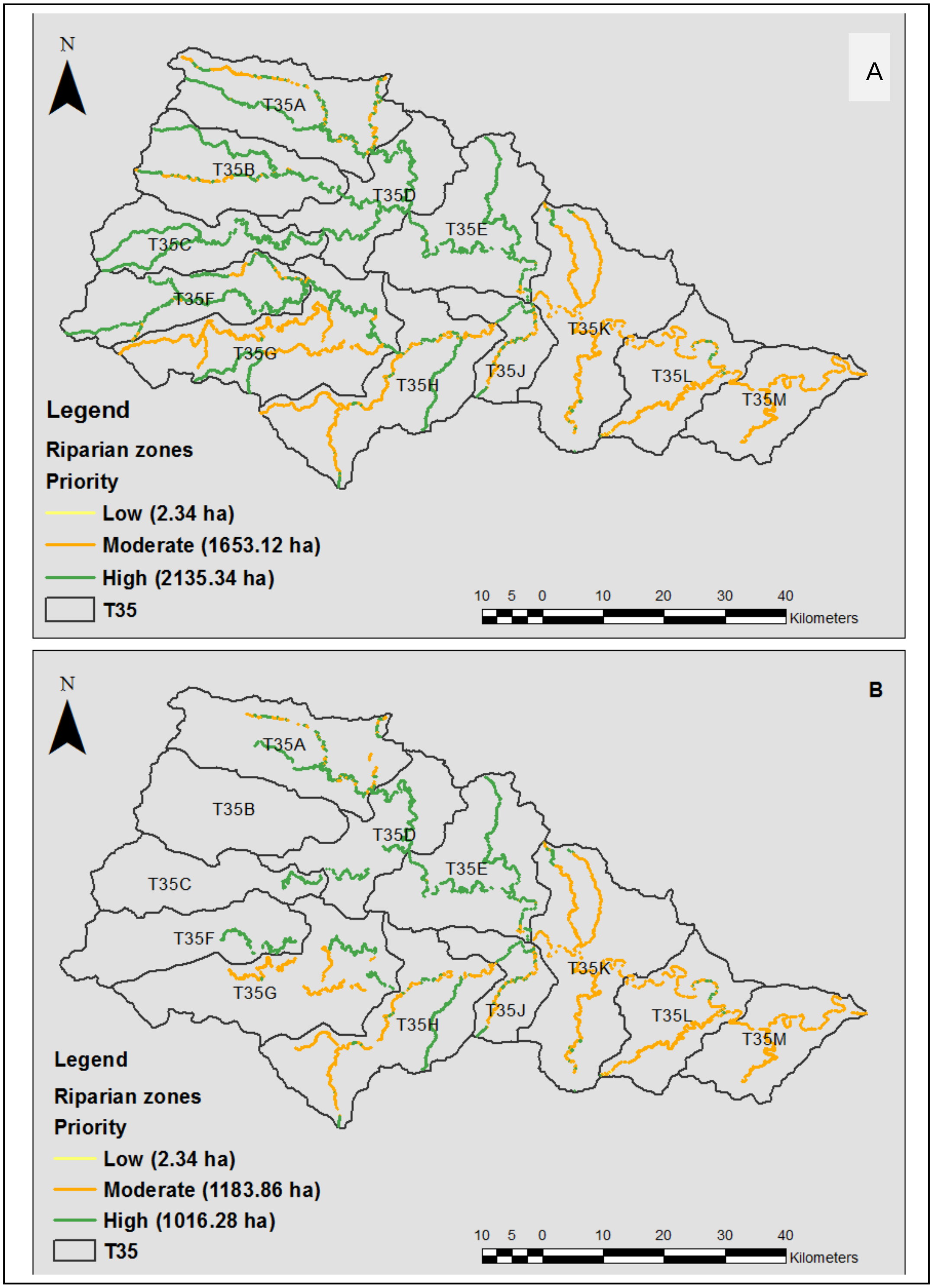


Figure 3-58 AHP model results for priority areas for riparian margins restoration in the Tsitsa catchment without (**top**) and with (**bottom**) inclusion of social benefit criterion. The priority overall ranking results are: 1-2 = low / poor suitability, 3 = moderate / fair suitability, 4-5 = high suitability

3.4.5.3 Prioritisation results for the Crocodile River catchment

The AHP results indicated that the most suitable EI areas coincided with the Inkomati-Usuthu SWSAs in the eastern sub-basins (Figures 3.59-3.62). Nearly 5,500 ha of wetlands composed of seepage and valley-bottom wetland types were suitable for flow regulation enhancement in the Upper Crocodile catchment (Figure 3.59). Of these, the AHP model detected 1.41% (or 76.95 ha) as suitable for improving flow regulation and social benefit in the catchment (Figure 3.59).

For abandoned cropland resources, the AHP model detected 1783.22 ha (for flow regulation improvement) and 1868.13 ha (for social benefits) (Figure 3.60). Only 335.03 ha were highly suitable for improving the catchment flow regulation service, while 124.65 ha were highly suitable for other local livelihoods (Figure 3.60).

The prioritisation of grasslands in the Upper Crocodile catchment (Figure 3.61) revealed that nearly 11 000 ha of highly suitable areas to improve flow regulation, 2 123 ha that could contribute to local livelihoods.

Restoration of 377.1 and 1132.2 ha of the prioritised riparian margins in the Upper Crocodile catchment would have some contribution to improve water flow regulation in the catchment (Figure 3.62). Between 31.59 and 607.77 ha of prioritised riparian margins could make a contribution to social benefits, if restored.

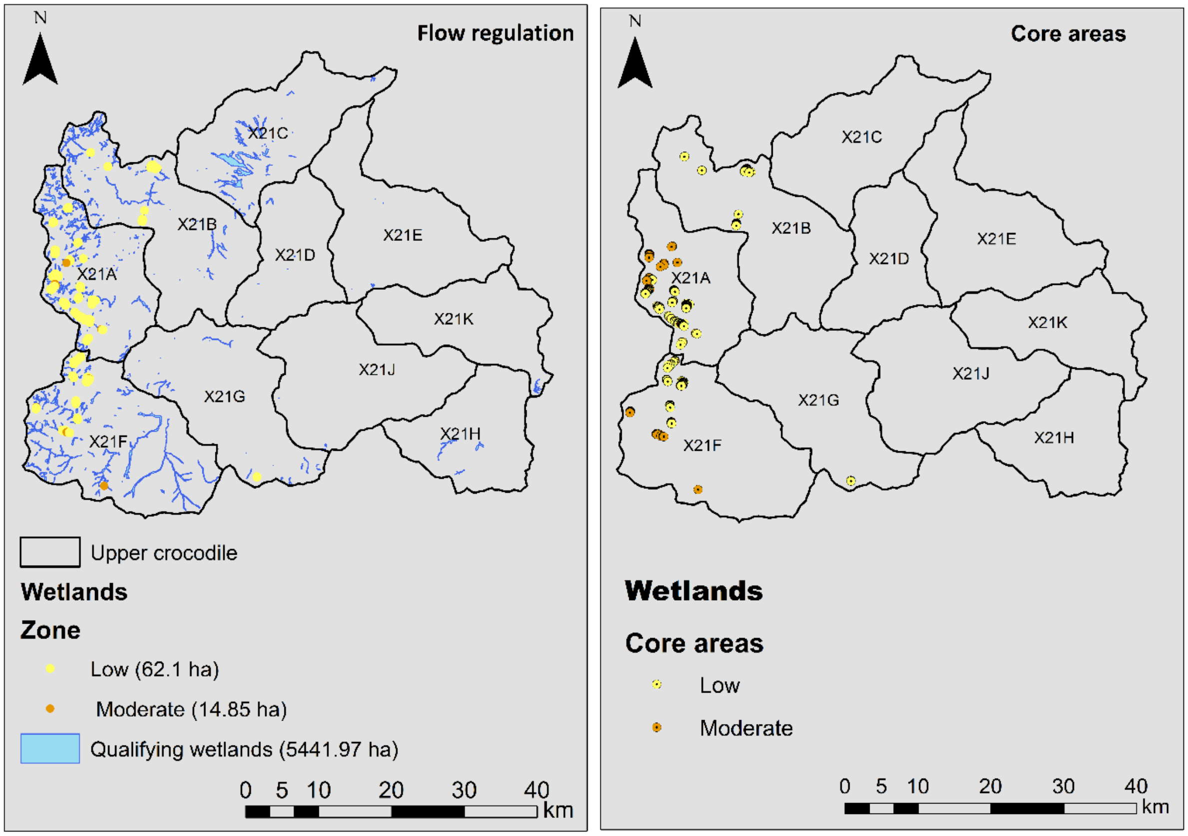
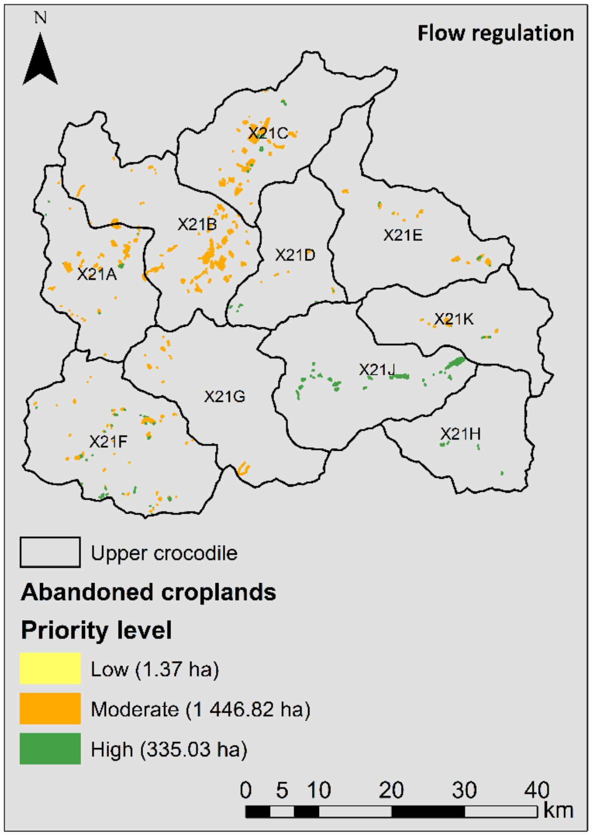


Figure 3-59 AHP model results for priority areas for wetland restoration in the Upper Crocodile catchment without (**left**) and with (**right**) inclusion of social benefit criterion. The priority overall ranking results are: 1-2 = low / poor suitability, 3 = moderate / fair suitability, 4-5 = high suitability



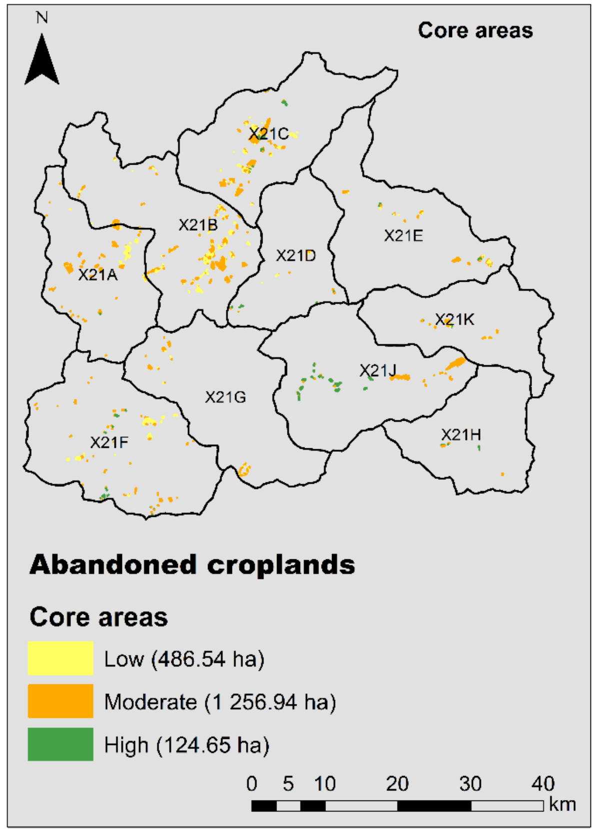


Figure 3-60 AHP model results for priority areas for abandoned cropland restoration in the Upper Crocodile catchment. The results are the same without and with inclusion of social benefit criterion since all croplands are considered important for livelihoods of communities. The priority overall ranking results are: 1-2 = low / poor suitability, 3 = moderate / fair suitability, 4-5 = high suitability

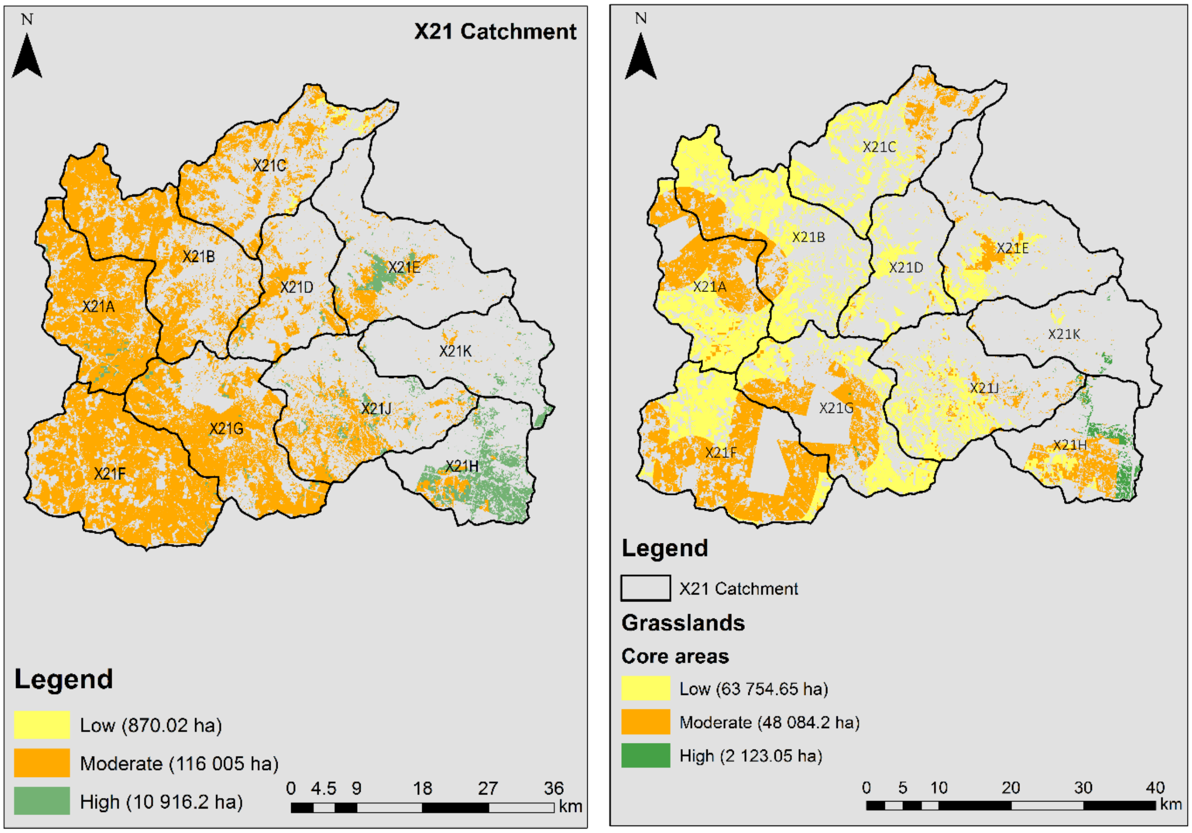


Figure 3-61 AHP model results for priority areas for grassland restoration in the Upper Crocodile catchment without (**left**) and with (**right**) inclusion of social benefit criterion. The priority overall ranking results are: 1-2 = low / poor suitability, 3 = moderate / fair suitability, 4-5 = high suitability

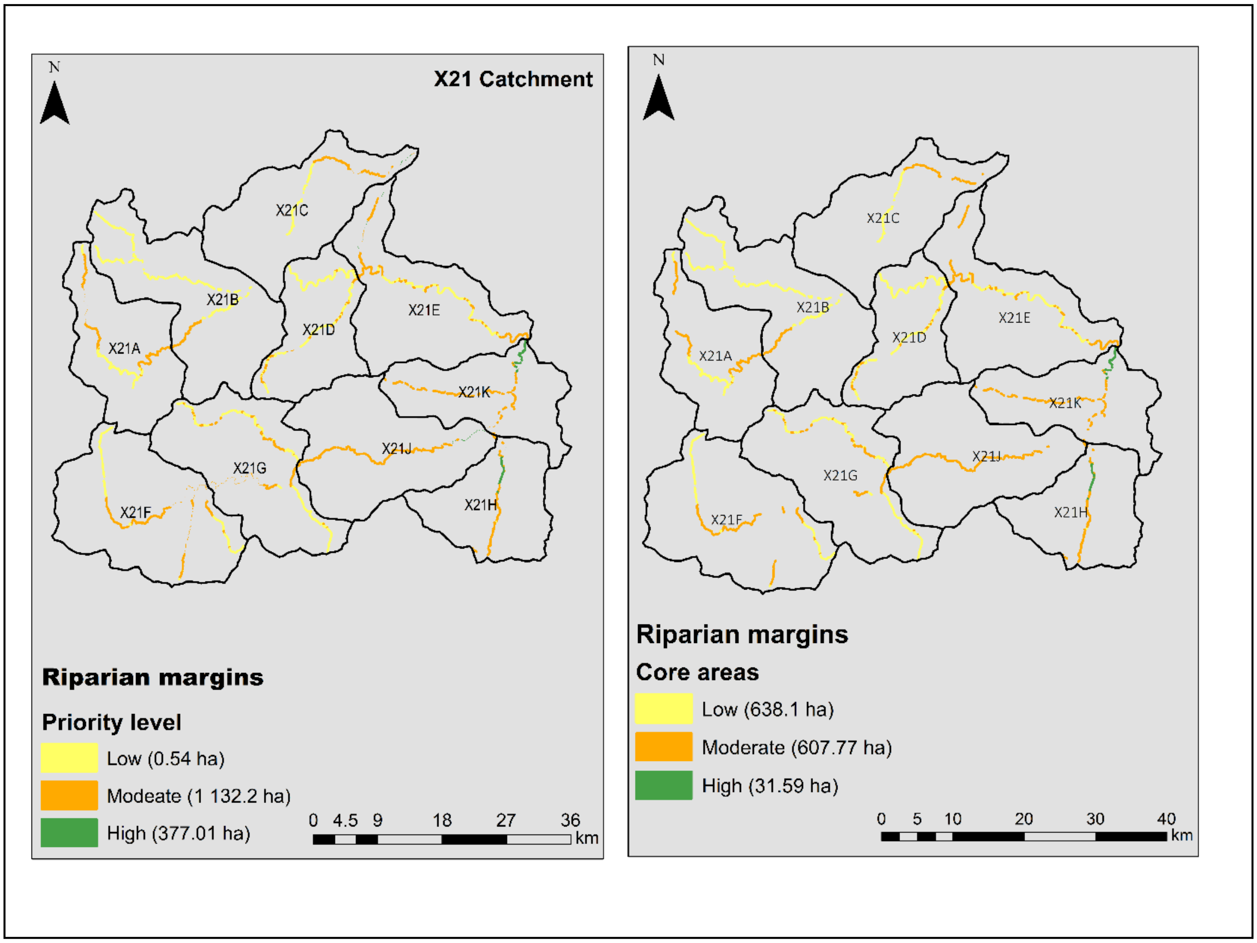


Figure 3-62 AHP model results for priority areas for riparian margins restoration in the Upper Crocodile catchment without (**left**) and with (**right**) inclusion of social benefit criterion. The priority overall ranking results are: 1-2 = low / poor suitability, 3 = moderate / fair suitability, 4-5 = high suitability

3.4.6 Discussion

This study sought to assess the environmental status of an upstream rural catchment by combining the SDG 15.3.1 sub-indicators using the recently produced Trends.Earth plugin (Conservation International, 2018). The plugin combines the three sub-indicators using the one-out, all-out statistical rule prescribed in the land degradation neutrality framework (Orr et al., 2017). Of the three sub-indicators in the Cacadu catchment, the most degradation was detected in the land productivity sub-indicator. Consequently, the SDG 15.3.1 indicator suggests that the three focal catchments were moderately to severely degraded (the extent of land area degraded ranges between 10-50% following FAO's (2002) degradation definition between 2000 and 2015. The human-induced improvement in the focal catchments was minimal (less than 5%).

Land productivity was the dominant type of degradation affecting the human-induced degradation status of the focal catchments. Since vegetation covers most of the terrestrial ecosystem, abnormalities in vegetation productivity have been used as an indicator of degradation at different scales in different parts of the world (Bai et al., 2008; Fensholt and Rasmussen, 2011; Bennett, Palmer and Blackett, 2012; Wessels, Van den Bergh and Scholes, 2012; Graw et al., 2017; Hoffman et al., 2018). The use of land productivity indicator alone for degradation assessment has been criticised for overlooking other forms of degradation (Gibbs and Salmon, 2015). Thus this study took into consideration two other degradation indicators as prescribed by the land degradation neutrality conceptual framework (Orr et al., 2017; Gonzalez-Roglich et al., 2019). Climate effects were removed in this study, and the significant decline detected for land productive capacity could be an indication of ecological response to plant phenological change (the seasonal timing for plant changes) (De Jong et al., 2011).

The degradation indicator study was conducted over a 15-year assessment period; however, the literature suggests that soil organic carbon reaches equilibrium after 20 years (Penman et al., 2003: 2.7). Therefore, the assessment period might have limited the detectability of soil organic carbon stock degradation. Secondly, this study was conducted at a tertiary catchment scale; therefore, the accuracy may be reduced in some land classes. For instance, the European Space Agency land cover dataset is a globally consistent and quick mechanism to classify land cover change at 300 m resolution (EuroSpace Agency, 2017; UNCCD, 2018). Thus the larger and higher contrast land cover classes (e.g. grasslands, tree-covered areas, croplands, and in some cases bare regions) have a higher probability of detection compared to smaller land cover classes such as wetlands. In summary, the degradation process in the catchments is predominantly localised, highlighting the relevance of the local scale for land management policy planning. Land cover and soil organic carbon stocks largely remained unchanged, while land productivity showed a declining trend, possibly due to natural and human-induced stress. Consequently, land productivity changes influenced the degradation results obtained, suggesting a new degradation process through a moderate reduction in biomass productivity. Therefore, the findings from this study emphasise the need to adopt management interventions in rural grassland ecosystems to protect the security of vulnerable rural communities. Based on the prioritisation findings and the land degradation neutrality framework, the high priority areas are recommended for EI investment to improve water flow regulation, and they would yield other ecosystem benefits for locals.

An application of a stakeholder informed GIS-AHP approach in four EI resources (wetlands, riparian margins, abandoned croplands and grasslands) helped prioritise suitable areas for restoration to improve water flow regulation in the focal catchments. The utility of stakeholder inclusive multi-criteria decision support has been demonstrated in the IAP prioritisation case study in the Western Cape (Forsyth et al., 2012). Values from diverse actors were combined with spatial datasets to prioritise over 300 quaternary catchments for clearing. Understanding social characteristics in the present study helped determine where EI investments could be targeted, similar to the prioritisation for IAP clearing (Forsyth et al., 2012) and the ecosystem service valuation (Favretto et al., 2016) case studies. The process followed in this study to produce the suitable areas EI for restoration was centred on the numerical overlay in a GIS platform to integrate the attributes and criteria. The numerical overlay requires consistent indicator ranges, for which this study used a 1-5 indicator range. The most significant observation is that a few areas have a high priority level to improve water flow regulation in catchments, and even fewer EI areas can contribute to local livelihoods if restored.

CHAPTER 4 ASSESSMENT OF HOW ECOLOGICAL INFRASTRUCTURE FACILITATES DROUGHT MITIGATION (AIM 3)

This chapter addresses Aim 3 of the project: *To provide an assessment of how the ecological infrastructure facilitates drought mitigation*.

4.1 South African research on how ecological infrastructure promotes flow regulation and mitigates droughts

The connections between catchment health (determined by land cover and land-use [or misuse that leads to land degradation]) and flow regulation ecosystem service have been envisioned by Le Maitre, Kotzee and O'Farrell (2014) as shown in Figure 4-1. The authors provide evidence for this conceptual model from various studies including work conducted on the degradation related to overgrazing and cultivation in the Little Karoo (Le Maitre et al., 2007). Le Maitre et al. (2014) tested this model in the fynbos biome with impacts of invasive plants (acacia and pine plantations) and concluded that there is increased risk of flood damage associated with the degradation due to these invasive plants. This risk was linked to increased soil water repellence and thus, increased overland flow in plantations after fires have gone through the area. The authors propose that the changes in flow regulation can be observed as changes in the quickflow and baseflow of flood hydrographs from a healthy catchment with strong flow regulation versus a degraded one with weak flow regulation (Figure 4-1). The long-term impacts of commercial forestry industry on streamflow, evaporation and deep soil water profiles was shown by a study in Two Streams catchment (near Pietermaritzburg) which found that wattle trees with roots as deep as 4.8 m can access groundwater (Clulow, Everson and Gush, 2011).

Here we summarise some of the South African research that supports the links between ecological infrastructure and flow regulation, and the projected impacts.

Mander et al. (2017) showed that rehabilitation interventions can maximise the benefits through investing in EI, and facilitate drought mitigation and improve ecosystem services. They used hydrological and economic modelling to investigate two systems, the Baviaanskloof-Tsitsikamma and uMngeni catchments, and two rehabilitation options (hillslope revegetation and removal of invasive plants). The authors concluded that rehabilitation, protection and maintaining priority ecological infrastructure would provide significant gains in baseflows and total streamflow. They also evaluated that the cost of these interventions were variable depending on the level of degradation but these costs were in the same order of magnitude as building dams or alternative water infrastructure.

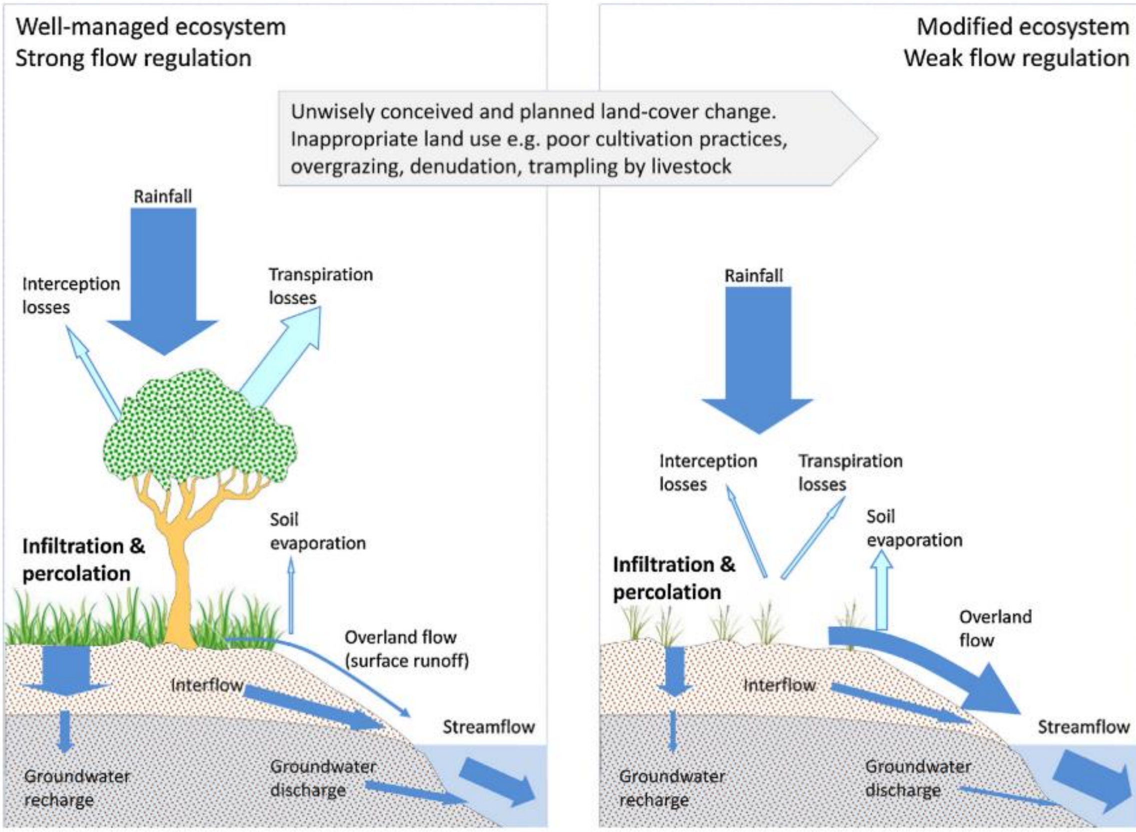


Figure 4-1 Elements of the flow regulation service, the processes that link them and how they are affected by land cover change and inappropriate land use (sourced from Le Maitre, Kotzee and O'Farrell, 2014: p. 173)

The work by Jeanne Nel and co-authors in Eden District supports the assertion that EI related interventions promote human well-being through adaption to climate change. Their research used scenario-based models with land cover and climate change drivers as inputs to identify the changes in four natural hazards, including droughts, for the Eden District (Nel et al., 2014). Their finding was that land cover change by humans is likely to increase natural hazards, and they promote land use management and support for healthy ecosystems as the way forward to reduce the probability and the impact of extreme events.

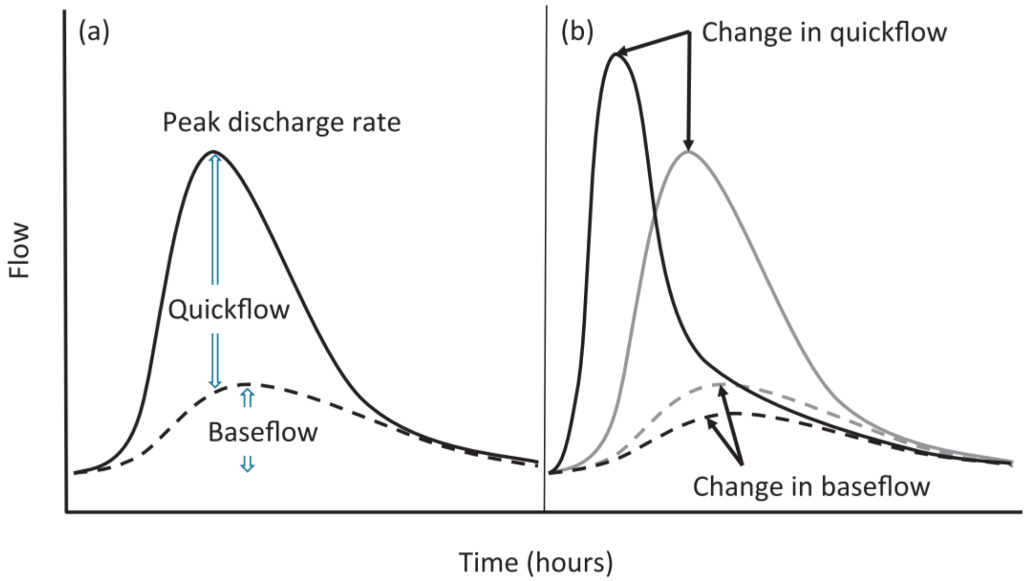


Figure 4-2 Comparison of quickflow and baseflow in the flood hydrographs from catchments with (a) strong and (b) weak flow regulation (sourced from Le Maitre, Gush and Dzikiti, 2015).

A set of three inland water resources related EI case studies is provided by Maze et al. (2019) as part of the National Biodiversity Assessment 2018 report. The three studies look at how EI is relevant for drought mitigation in Cape Town, water security in uMngeni river catchment and EI provides socio-economic benefits in uMzimvubu catchment. The Cape Town study looks at the impacts of invasive plants and degradation of wetland ecosystems in the Berg and Breede River catchments and provides evidence that catchment restoration would be cheaper than the other proposed options of desalination or groundwater extraction, for increasing water supply. The second EI study showcases the uMngeni Ecological Infrastructure Partnership (UEIP) that has prioritised sub-catchments for protection and restoration using hydrological modelling and cost-benefit analysis. This study also found investment in EI as a more cost effective approach that also has the benefit of increasing the lifespan of dams that are silting up. The final EI study is located in uMzimvubu catchment, a SWSA and a Freshwater Ecosystem Priority Area (FEPA), where the uMzimvubu Catchment Partnership Programme (UCPP) is working on rangeland restoration and alien plant management. Land degradation in this catchment has been linked increased sediment connectivity due to presence of gullies and incised river channels (van der Waal and Rowntree, 2018). The report also presents the proposed idea of protecting montane grasslands in the upper catchment along the South Africa/Lesotho boundary as one of the solutions moving forward.

A study by Warburton, Schulze and Jewitt (2012) applied the ACRU hydrological model to determine the impacts of land use change on the hydrological response of three catchments (uMngeni, Luvuvhu and Upper Breede). They found the relationships to be complex and not linear, e.g. streamflow contributions from different land uses were not proportional to the relative area of the land use. One of the analysis they conducted for a hypothetical catchment found that the mean monthly ratios of stormflow to total streamflow (baseflow plus stormflow) from degraded vegetation areas were higher than those from natural vegetation.

Other hydrological modelling research in uMngeni catchment has found that overgrazing (leading to degraded vegetation) and black wattle invasion can result in reduction in dry season baseflows per hectare due to reduced interception and infiltration (Hughes et al., 2018b). The authors also found higher quickflows per hectare from degraded vegetation but reduced quickflows from invasive plant areas compared to natural vegetation possibly due to higher interception and transpiration.

4.2 Hydrological modelling methodology

The Pitman Model (Pitman GWv3 Model) was selected to represent the runoff regime in natural vs modified catchment areas (Hughes, 2004; Kapangaziwiri and Hughes, 2008) in two of the case study catchments. The Pitman GWv3 Pitman Model is a conceptual monthly time-step hydrological model that is typically applied at a quaternary catchment scale (50 to 1 000 km^2) to simulate natural flows and is hosted by the SPATSIM software (Spatial and Time Series Information Modelling) (Hughes and Forsyth, 2006). The model has been used widely within southern Africa (Hughes, 2013). A detailed description of the Pitman rainfall-runoff model is available in Hughes (2004, 2013). The following is a summary of the methodology. Please refer to the theses by Mr Xoxo and Ms Mahlaba for full details for model setup for White Kei and Tsitsa catchments.

The catchment conditions were obtained from the 30 m resolution 1990 to 2018 NLC Change dataset and the 20 m resolution 2018 NLC datasets (Department of Environmental Affairs, 2019) for the quaternary catchments. The 1990 to 2018 NLC Change Assessment dataset was chosen for its consistent land cover interpretation, making it similar to the 2018 NLC dataset. Using land cover change over 28 years, this study consolidated the 72 land cover classes in the datasets into two main land cover types: natural and modified (Table 4-1). The natural land cover classes included grasslands, and native tree-covered areas. Wetlands were represented as riparian areas.

Table 4-1 Conversion of 1990 to 2018 and 2018 National Land Cover and UNCCD Land Cover categories into flow regulation scenario classes for the rainfall-runoff comparison.

National Land Cover categories	UNCCD categories	New legend
Indigenous Forest Thicket/ dense bush Natural Wooded Land	Tree-covered areas	Natural land/Afforested (if tree-cover was a result of conversion from other land types)
Planted forest		Afforested (Modified land)
Shrubland Grasslands	Grassland	Natural land
Wetlands	Wetlands	Wetlands (Riparian areas)
Barren Land	Other lands	Natural land
Eroded Lands Mines		Modified land
Permanent Orchards Permanent Vines Commercial Annual Pivots Commercial Annual Non-Pivot Cultivated Subsistence	Cropland	Modified land
Built-up Residential All Built-up Smallholdings Built-up Commercial Built-up Industrial	Artificial surfaces	Modified land
Waterbodies	Waterbodies	Waterbodies (Dams)

The study used historical time-series rainfall data from the 2012 Water Resources (WR2012) dataset, which covered the period from 1920 to 2009 (Bailey and Pitman, 2015). Since the WR2012 data ends in 2009, and the assessment runs until 2018, remotely sensed data alternatives (Climate Hazards Group Infrared Precipitation with Stations [CHIRPS] and Tropical Rainfall Measuring Mission [TRMM]) were considered to complete the dataset. Comparison of these datasets over the overlap period from 1981 showed that, in the White Kei catchment, the CHIRPS dataset (Funk et al., 2015) corresponds well with the WR2012 in comparison to the TRMM dataset (Huffman et al., 2007) which often exceeded WR2012. Interestingly, the opposite was true for the Tsitsa catchment and here the TRMM data were used to extend the timeseries (see the theses by Mr Xoxo and Ms Mahlaba for full details).

A conceptual representation of how the EI modification processes affect water balance was adopted by Mr Xoxo from a review on the impact of urbanisation on groundwater recharge by

Schirmer, Leschik and Musolff (2013). Since this study is not focused on recharge, the diagram was revised to reflect the impact of land modification on flow regulation as outlined in ecohydrology literature. Four anthropogenic induced land modifications, defined as afforestation, cropland expansion, expansion of settlements, and eroded surfaces, were detected in the catchments (Figure 4-3). All the land cover modifications are expected to lead to increments in evapotranspiration and quickflow and reductions in groundwater recharge and baseflow. The land modifications should have a variable influence on infiltration, interflow and groundwater usage.

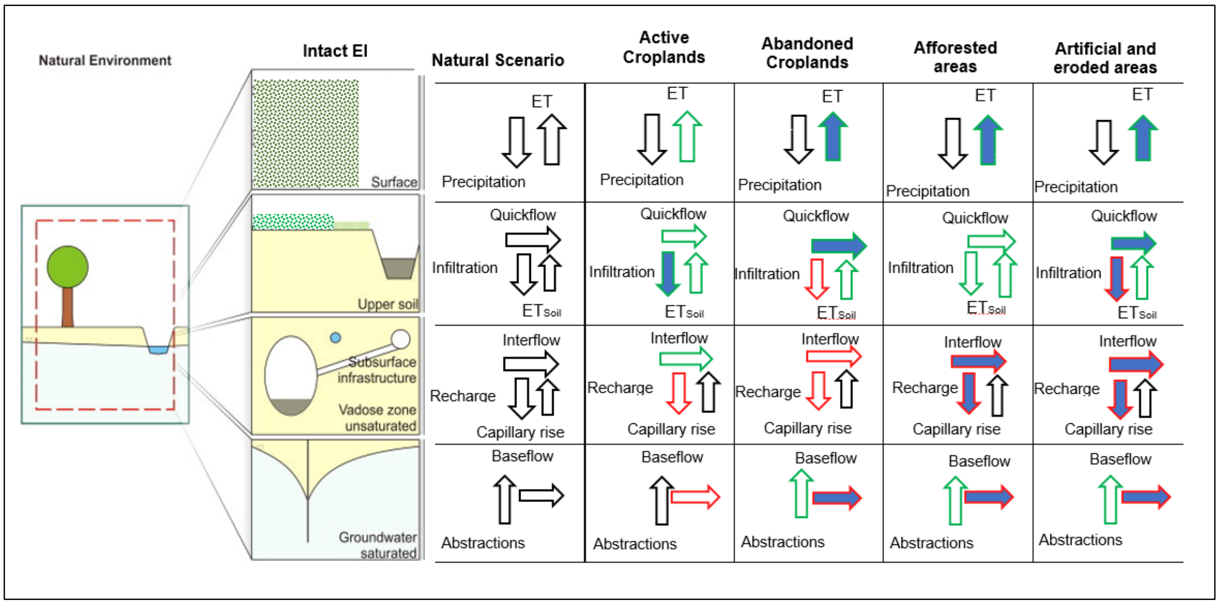


Figure 4-3 Simplified impact of major rural land modification processes in catchment hydrology (modified from Schirmer et al., 2013). The changes in water balance components are denoted by arrow colours (**black** = natural; **green** = increase in volume; **red** = decrease in volume; **blue fill** = severe modification). Quickflow is a combination of surface and rapid sub-surface runoff

4.3 Modelling results and discussion

4.3.1 Hydrological modelling results for White Kei catchment

The simulated streamflow for the Natural, 1990 land cover and 2018 land cover scenarios covering the years 1920 to 2019 are shown using flow duration curves by quaternary catchment in Figure 4-4. The general impact of land modification in the White Kei catchment was higher quickflow (surface runoff and fast released subsurface flow) and a reduction in the magnitude of dry season low flows compared to the Natural Scenario. Periods of no-flow covering at least 5% of the time for the natural land cover in the White Kei catchment (S10A-D, S10F-G, and S20A) indicate seasonal streams in the catchment, but land modification expands the duration of these by a range of 10.94 to 21.21% of the time. The areas dominated by intermittent streams are typically symbolised by a discharge threshold below 0.05 cumecs, whereas those dominated by perennial streams (S10E, S10H, S10J, and S20B-D) have a low flow discharge threshold ranging between 0.5 to 1.04 cumecs. Land modification in most parts of the White Kei catchment with a dominance of intermittent streams further reduces the catchments' ability to delay rainwater for release in the dry season, shown by the steep falling gradient.

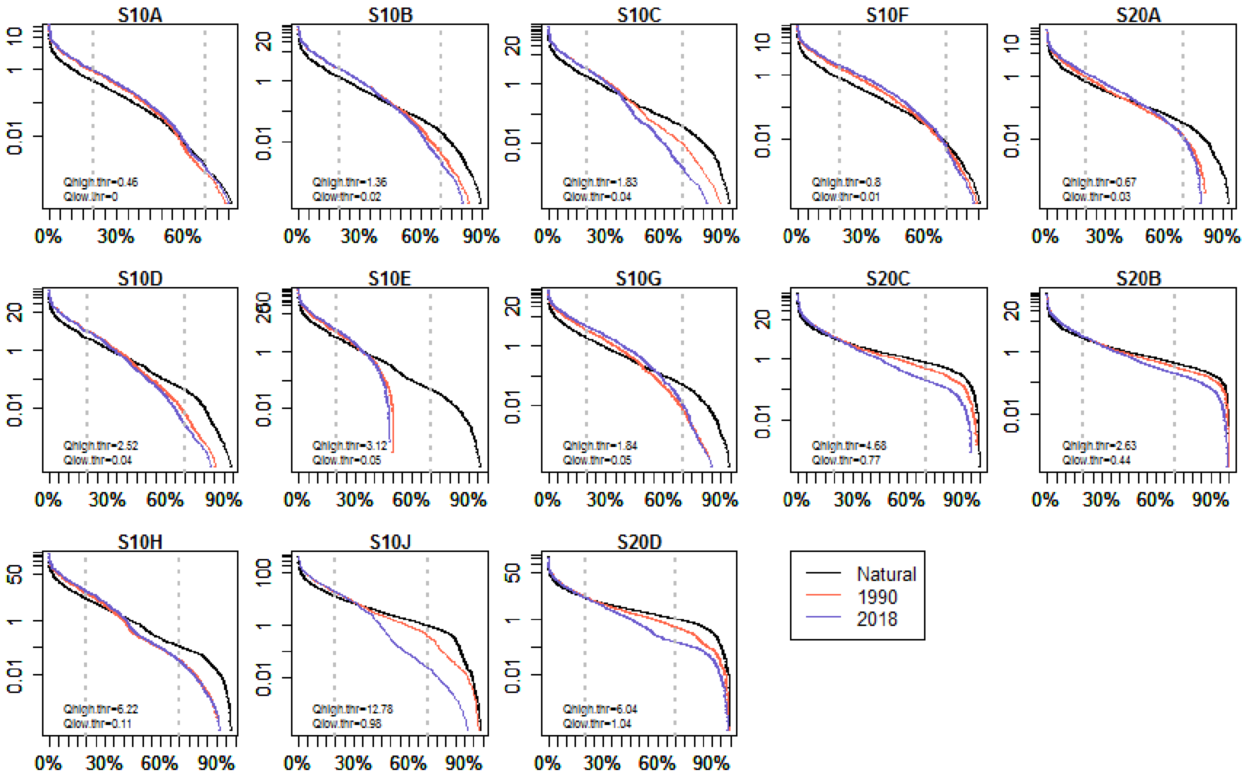


Figure 4-4 Estimated long-term simulated streamflow expressed as monthly distribution curve under the three scenarios of land modification in each quaternary catchment of the White Kei catchment. The plots have been arranged based on landscape from high to low reach. The vertical axis shows discharge (in cumecs). The horizontal axis shows % exceedance time

4.3.2 Hydrological modelling results for Tsitsa catchment

The simulated streamflow for the Natural and 2018 land cover scenarios covering the years 1920 to 2019 are shown using flow duration curves by quaternary catchment in 4-5. Similarly to the White Kei, the general impact of land modification in the Tsitsa catchment was higher quickflow (surface runoff and fast released subsurface flow) and a reduction in the magnitude of dry season low flows compared to the Natural Scenario. Under the natural simulation, there are no periods of zero flow (in some catchments the flow is minimal but it never reaches zero flow). With the introduction of land use determined from the 20 m resolution 2018 NLC datasets (Department of Environmental Affairs, 2019), the outflow from many of the quaternary catchments becomes seasonal with periods of no-flow up to 10% of the time. Land modification (significant afforestation, woody encroachment and degraded land – from overgrazing and abandoned cultivation) is significant in the Tsitsa catchments and these changes have reduced the catchments' ability to delay rainwater for release in the dry season, shown by the steep falling gradients.

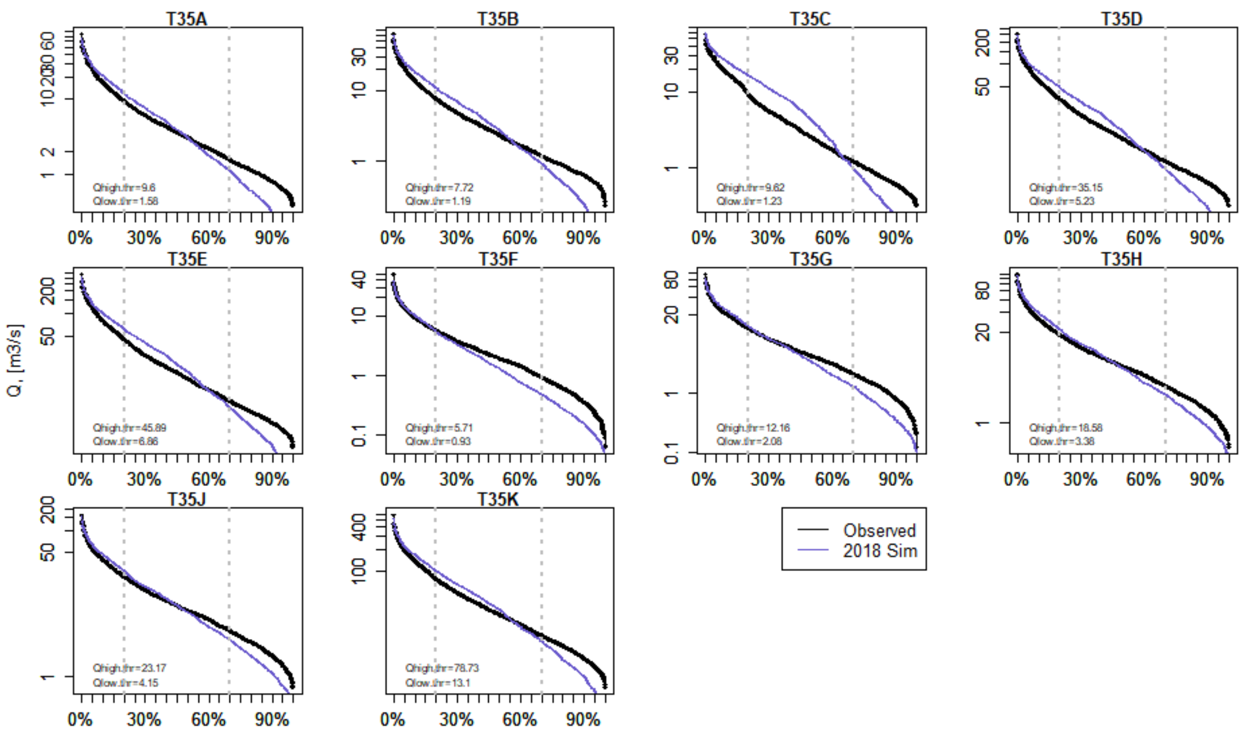


Figure 4-5 Estimated long-term simulated streamflow expressed as monthly distribution curve under the two scenarios of land modification in each quaternary catchment of the Tsitsa catchment. The plots have been arranged based on landscape from high to low reach. The vertical axis shows discharge (in cumecs). The horizontal axis shows % exceedance time

4.3.3 Discussion

The results of the White Kei and Tsitsa hydrological modelling demonstrate that land modification in this environment reduces the catchment's capacity to delay rainfall from quickly reaching streams during the wet season. While the observed data (streamflow) in the White Kei were of poor quality and hence verification of the model outputs was difficult, two stream flow gauges in the Tsitsa catchment (T3H009 and T3H006) produced data of sufficient quality to ensure the hydrological model was representing stream flows sufficiently (T35C – T3H009: Nash-Sutcliffe Coef. Eff. Nat 0.73 and Log 0.705; T35K – T3H006: Nash-Sutcliffe Coef. Eff. Nat 0.704 and Log 0.655). It should be noted that it was endeavoured to set up the model to reflect processes and catchment characteristics as sensibly as possible (see the theses by Mr Xoxo and Ms Mahlaba for full details).

Both study catchment's steep slopes can be prone to quickflow dominance and lead to soil erosion. Catherine Hughes' research in uMngeni catchment noted that natural vegetation stabilises the soils and increases soil water retention (Hughes et al., 2018b). This results in higher quickflow from areas with degraded vegetation compared to natural vegetation.

The simulated surface runoff dynamics due to land modification support earlier findings in the Olifants catchment (Gyamfi, Ndambuki and Salim, 2016), where a significant reduction in rangelands and increase in croplands led to nearly 50% more surface runoff. Findings by Gyamfi et al. (2016) are consistent with other literature in South Africa (Rebelo et al., 2015; Mander et al., 2017; Hughes et al., 2018b). Despite the differences in methodology and study contexts, the studies collectively agree that land cover alterations such as those in the White Kei and the Tsitsa catchments combined with climate change impacts intensify surface runoff and result in less resilient catchments regarding drought.

CHAPTER 5 KNOWLEDGE GAPS AND RECOMMENDATIONS FOR RESEARCH

The role of ecological infrastructure for environmental, economic and social well-being is centre stage globally due to the threats to water security and water quality issues both presently and in future according to projected water scarcity under future climate. Collaboration between researchers, practitioners and government departments is slowly unlocking the potential investments in ecological infrastructure There exist global and national frameworks which can assist in making a case for why investing in EI is crucial (Cumming et al., 2017). Better understanding and quantification in regards to the role of healthy EI for the flow regulation function is important for water security and drought mitigation, and this study is one of the contributing projects investigating this in three focal catchments. Section 5.1 provides the response strategy for improving water security using EI and Section 5.2 is on knowledge gaps and future research.

5.1 **Response strategy for improving water security using ecological infrastructure**

5.1.1 National and international strategies

> All economic activity ultimately depends on services provided by nature, making it an immensely valuable component of a nation's wealth. It's estimated that, globally, nature provides services worth around US$125 trillion a year. Governments, business and the finance sector are starting to question how global environmental risks – such as increasing pressure on agricultural land, soil degradation, water stress and extreme weather events – will affect the macroeconomic performance of countries, sectors and financial markets.
>
> WWF (2018: p. 17)

> Preventing degradation is much cheaper in the long run than permitting it, and then later paying for the impacts and restoration. In many landscapes we no longer have that choice. Yet, there is hope. In all ecosystems assessed, examples of successful damage rehabilitation can be found. Rehabilitating damaged lands is cost-effective despite the high initial price, if the full long-term costs and benefits to society are considered.
>
> WWF (2018: p. 42)

The United Nations Sustainable Development Goals (SDGs) are global targets for guiding environmental protection, reducing inequality, and for stimulating economic growth (United Nations, 2015a) and have been adopted by the South African government (https://sustainabledevelopment.un.org/memberstates/southafrica). Statistics South Africa has launched an online data portal for tracking progress towards these goals (http://www.statssa.gov.za/?p=12813). Two SDGs are specifically aimed at land management in terms of sustainable land cover change (SDG 15 Life on Land) and at water security (SDG 6 Clean Water and Sanitation), and SDG 13 (Climate Action) links these with the impacts of climate change. South Africa's 2030 agenda for addressing poverty and inequality laid out in the National Development Plan (NDP; South African National Planning Commission, 2012) is strongly aligned with these three SDGs (Cumming et al., 2017). Table 5-1 provides details of this alignment in terms of the NDP objectives and actions, highlighting the focus on protection and management. Cumming et al. (2017) note that preventing land degradation and restoring degraded rangelands is considered an adaptive water management strategy for drought. The effective management of catchment EI to ensure that hydrological services are maintained is also necessary for achieving SDG 14 (Life below water). This is particularly critical given the poor state of South Africa's river and wetland systems and increasing land degradation (Skowno et al., 2019a).

Table 5-1 Links between SDGs and South Africa's National Development Plan (NDP) focus areas that are relevant to the current project. Source: Cumming et al. (2017) and South African National Planning Commission (2012)

SDG	Agenda 2030 NDP Focus	Relevant NDP objectives	Relevant actions
SDG 6. Ensure availability and sustainable management of water and sanitation for all	Chapter 4: Economic Infrastructure	Ensure that all people have access to clean, potable water and that there is enough water for agriculture and industry, recognising the trade-offs in the use of water. Reduce water demand in urban areas to 15 percent below the business-as-usual scenario by 2030.	A comprehensive management strategy including an investment programme for water resource development, bulk water supply and wastewater management for major centres by 2012, with reviews every five years.
SDG 13. Take urgent action to combat climate change and its impacts	Chapter 4: Economic Infrastructure		
SDG 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss	Chapter 5: Environmental Sustainability and Resilience	A set of indicators for natural resources, accompanied by publication of annual reports on the health of identified resources to inform policy. A target for the amount of land and oceans under protection (presently about 7.9 million hectares of land, 848 Km of coastline and 4 172 square kilometres of ocean are protected).	Put in place a regulatory framework for land use, to ensure the conservation and restoration of protected areas

The South African National Biodiversity Institute (2014) framework views investment in EI as a strategy for accruing various benefits to society including water and food security. The investment in EI can be through **maintenance of functioning EI**, in addition to **restoration of degraded ones** (South African National Biodiversity Institute, 2014). The framework provides the foundation for linking the investment in EI to the National Development Plan 2030, specifically action 7 (public infrastructure investment focused on transport, energy and water that takes account of disaster risk reduction and protection of freshwater ecosystems) and action 8 (interventions such as restoration and maintenance for ensuring environmental sustainability and resilience to future shocks) (see Cumming et al., 2017). The SANBI framework notes various benefits to society though investment in EI, including increased water yield, flood risk reduction, improved water quality, decreased exposure to natural disasters, improved carbon balance, improved grazing productivity, and improved food and livelihood security (Figure 5-1).

Given all these strategic goals and national development imperatives and the benefits of restoration described in Chapter 2, there should be strong incentives to invest in effective management and restoration of land to sustain these critical hydrological services. Yet there isn’t. Although the Natural Resource Management Programmes within DEFF are investing in invasive alien plant clearing and restoration, their combined investment is only a fraction of the investment required to restore the EI in South Africa (Marais, 2015). One of the key reasons for this is that these priorities are competing against many other priorities such as industrialisation, education and, most recently, investment in rebuilding an economy struggling to recover from the impacts of the lockdown and the redirection of investment into health to deal with Covid-19.

An alternative way forward is the LandCare programme that was initiated by the former Department of Agriculture (now DEFF) with the aim to mainstream biodiversity in agriculture, forestry and fisheries policies (such as, the Conservation of Agricultural Resources Act 43 of 1983) in cooperation with NGOs, private sectors and provincial government practices (Everson, Everson and Zuma, 2007; Government of South Africa, 2015). This involved promoting sustainable rangeland management and conservation agriculture to reduce the impacts of cultivation on soil loss and to protect cultivated lands from become degradation sources. This form of public-private partnerships has also been used by DEA-NRM (e.g. uMzimvubu Catchment Partnership Program (UCP), Umngeni Ecological Infrastructure Partnership, Tsitsa Project, WRC Green Village), and is being promoted through partnerships between the private sector and NGOs (e.g. WWF, Meat Naturally, AWARD). Participatory partnerships such as these offer the affected people agency and capacity are essential bottom up initiatives that coupled with top-down support can be successful way forward that support sustainable land management and the building of sustainable livelihoods.

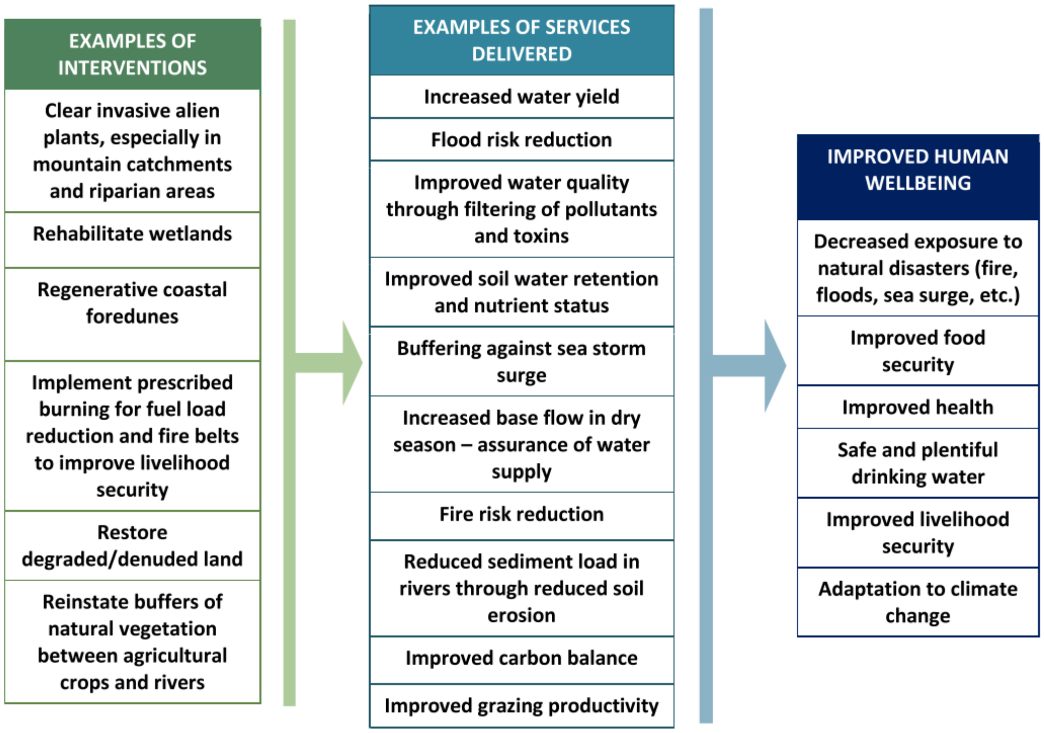


Figure 5-1 Examples of services and benefits derived by society because of investment in EI (sourced from South African National Biodiversity Institute, 2014).

5.2 Knowledge gaps and key areas of research going forward

Our knowledge in the area of land degradation and water security is still developing. Here we have collated some of the knowledge gaps and key areas of research.

5.2.1 Research on mapping and monitoring the consequences of degradation

- Mapping of changes in degradation over time and at relevant spatial scale and resolution (Montanarella, Scholes and Brainich, 2018)
- Information on land use change and threats to water quality and water availability (Department of Environmental Affairs, 2017b)
- Consequences of land degradation on freshwater ecosystems (Montanarella, Scholes and Brainich, 2018)
- Potential for land degradation to worsen climate change (Montanarella, Scholes and Brainich, 2018)

- Improved estimation and mapping of areas undergoing desertification (Intergovernmental Panel on Climate Change [IPCC], 2019)
- Quantification of the impacts of land uses, land degradation and loss in biodiversity on ecosystem service generation and delivery, particularly for vulnerable communities (Le Maitre, O'Farrell and Reyers, 2007)
- Understanding how invasions/plantations can enhance the effects of prolonged droughts and create lags in recovery from drought due to the time required by depleted soil moisture balance to recover from alien tree invasion, i.e. furthering the work done under long-term studies in Two Streams catchment by Colin Everson and Alistair Clulow.

5.2.2 Benefits and monitoring of rehabilitation

- Quantification of benefits of different types of restoration on water supplies using suitable indicators, e.g. various Department of Environmental Affairs: Natural Research Management's (DEA:NRM) programmes (https://www.environment.gov.za/projectsprogrammes#workingfor; accessed 15 Sep. 2019) including Working for Wetlands, Working for Ecosystems, and Working for Water (van Wilgen and Wannenburgh, 2016)
- Long-term monitoring of hydrology and EI links pre and post-restoration (Mander et al., 2017; Van der Waal and Rowntree, 2018)
- Research on increased resilience of water supply systems through non-engineered measures (Department of Environmental Affairs, 2017b)
- Influence of wetland rehabilitation on water availability (Department of Environmental Affairs, 2017b)
- Research on vulnerable communities and infrastructure that are more resilient to climate change impacts associated with water (Department of Environmental Affairs, 2017b)
- Economics of investing in ecological infrastructure for the study catchments similar to Jewitt et al. (2020)

5.2.3 Effective and integrated implementation

- Assessing the relative importance of situations that will allow avoiding, reducing and reversing land degradation, under various social, economic, cultural and governance contexts (Montanarella, Scholes and Brainich, 2018)
- Effective mechanisms for raising awareness and behaviour change of actors (Montanarella, Scholes and Brainich, 2018) and robust methods of conflict resolution (Shackleton et al., 2017)
- Effective incorporation of local peoples' knowledge on future scenarios (Sigwela et al., 2017).
- Spatial models and change scenarios for biodiversity and ecosystem services and the implications of various scenarios (Montanarella, Scholes and Brainich, 2018)

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APPENDIX 1. PARTICIPATORY GIS METHOD DETAILS FOR MACHUBENI VILLAGES

Report prepared by MSc student Mr Sinetemba Xoxo

A Participatory Geographical Information System (PGIS) exercise (Reed, Dougill and Baker, 2008) was conducted in Machubeni to verify and prioritise socio-spatial data of the focal resources. The approach used in the case study area employed the direct-to-digital (D2D) PGIS method (DeRoy, 2016) to verify key resources that had been identified by previous workshops by GEF team, and to help identify priority land covers based on stakeholder views.

Workshop design

Two group meetings were held: group meeting 1 (WS1) for the villages on the eastern side of the case study area involving stakeholders from Platkop and Gxojeni sub-villages with 15 participants, and group meeting 2 (WS2) for the western side villages involving stakeholders from Qhoboshane, Boomplaas and Helushe sub-villages with 25 participants (Attendance Register at the end of this appendix). The participatory mapping group meetings spanned over two days with one half-day group meeting for each side. The group meetings took a form of facilitated discussions with the guidance of a semi-structured interview schedule and base maps of project sites with previously mapped key resources.

Recruitment of participants

The key user groups that were recruited by means of purposive sampling strategy (Sisitka and Ntshudu, 2017) based on their interests in terms of natural resource use in the study area, were invited for the group discussions. The identified participants representing the larger community were the farmers' association and village land committees with stakeholders who are aged 18 and over. The headmen and sub-headmen were also invited, but the headman from WS1 asked for a separate meeting for a quick briefing since he had other commitments during the week. The participants were expected to have lived in Machubeni for over 10 years.

Participatory mapping process

Prior to the participatory mapping process, the GEF project personnel offered welcome speeches. Then an IsiXhosa speaking facilitator used the informed consent document (available at the end of this appendix) to (i) clearly explain the purpose of the group discussion, (ii) address the informed consent, and (iii) explain the expected outcomes to all participants. The facilitator also provided a breakdown of the workshop schedule. Data were collected by means of semi-structured guidance in an open group session that consisted of three questions viz.:

1. Key natural resources

- Using the map (Image 1; Image 2; Image 3; Image 4; Image 6), please verify if the areas shown therein are representative of all the areas you said you value the most.

For croplands and riparian margins, stakeholders were not asked to redraw polygons because these can be extracted from spatial datasets of river shapefiles using ArcGIS tools. Instead, participants simply shared their views regarding these two ecosystems.

2. Priority EI focal resource areas

- In which location is the most useful [*key resource name*]?

Resources that were included in the exercise: Abandoned croplands (Image 1; Image 4)*, Rangelands* (Image 2; Image 5)*, Wetlands* (Image 3; Image 6)*; and Riparian areas*

- Why are the identified locations ranked as the most important or least important resources?

Verification and Validation

Popular place names in the area were used as feature markers (or landmarks) for the participants to locate themselves in the maps, for example, schools and mountain ridges as shown in images below. The first step of the workshop was to ask participants to verify areas they deem important for their livelihoods in Machubeni using the identified key resources data. After verifying the key resources, participants were prompted to share their views on which resources they value the most and what criteria defined how they valued the resource area. The stakeholders were asked to define the relative importance of the resources into two classes only (less important and more important) because the characterisation was not for statistical measurements but to obtain qualitative stakeholder views.

Secondly, Mr Xoxo (MSc student) conducted field surveys with the help of two locals who are familiar with the surroundings of both WS1 and WS2 villages. The purpose of this field survey was to accurately locate the target resources that had not been addressed by previous workshops (relating to wetlands, springs and boreholes) and to confirm the locations for all the higher priority rehabilitation sites, as identified by the stakeholders. While conducting ground-truthing, the researcher took photos and GPS coordinates of the resources using a camera and an electronic GPS locator, in order to assist with assigning a coarse ecological state of the resources.

Ethics for human subjects

This work adheres by the university research guidelines and was reviewed under the Human Ethics protocol by the Rhodes University Ethics Standards Committee. Ethics were granted by the committee as a Participatory GIS workshop for Macubeni-0448, May 2019.

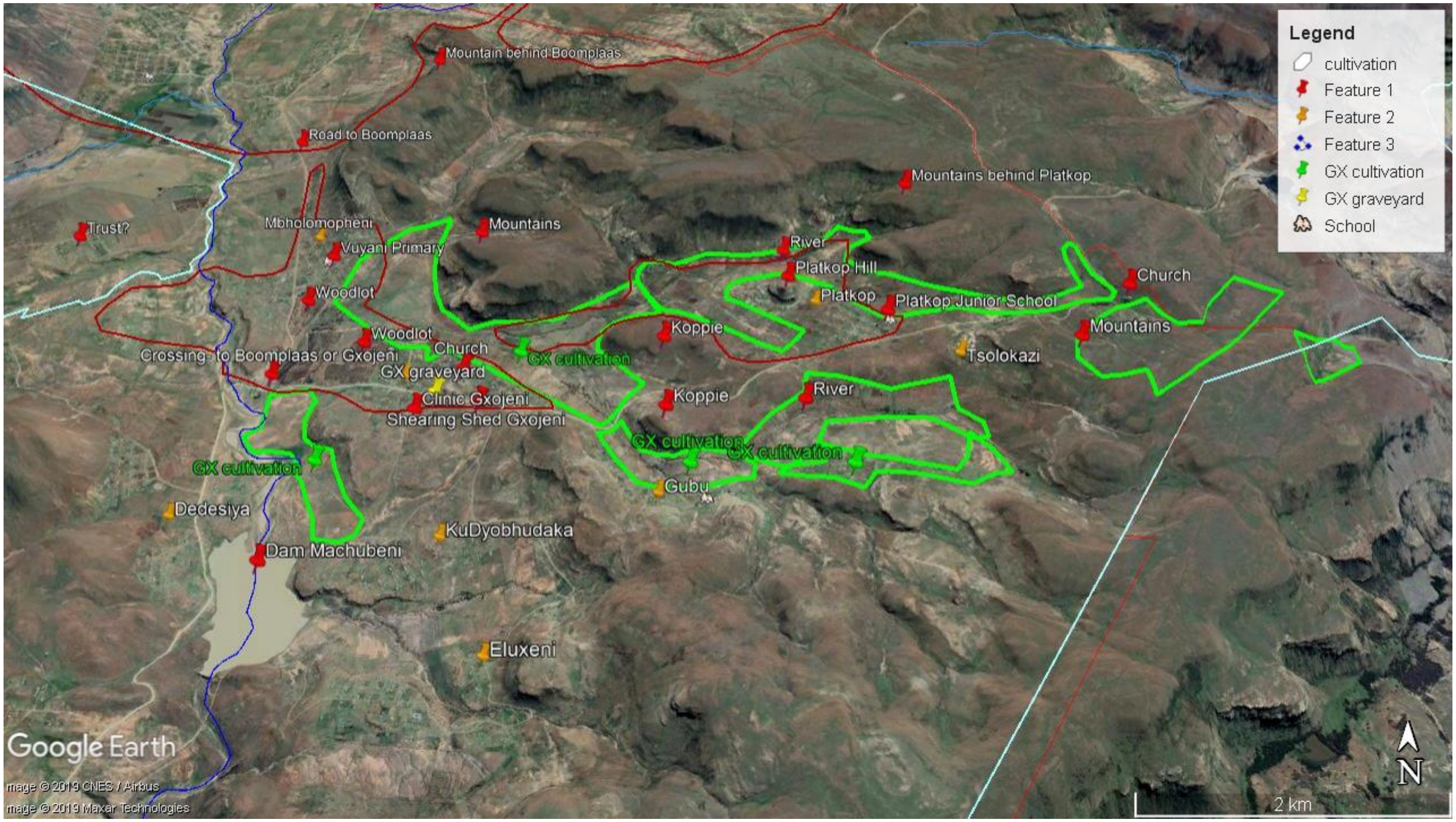

Image 1: Screenshot of the Google Earth base map for WS1 croplands. Red polygon = Village boundaries; green polygon = cultivated areas.

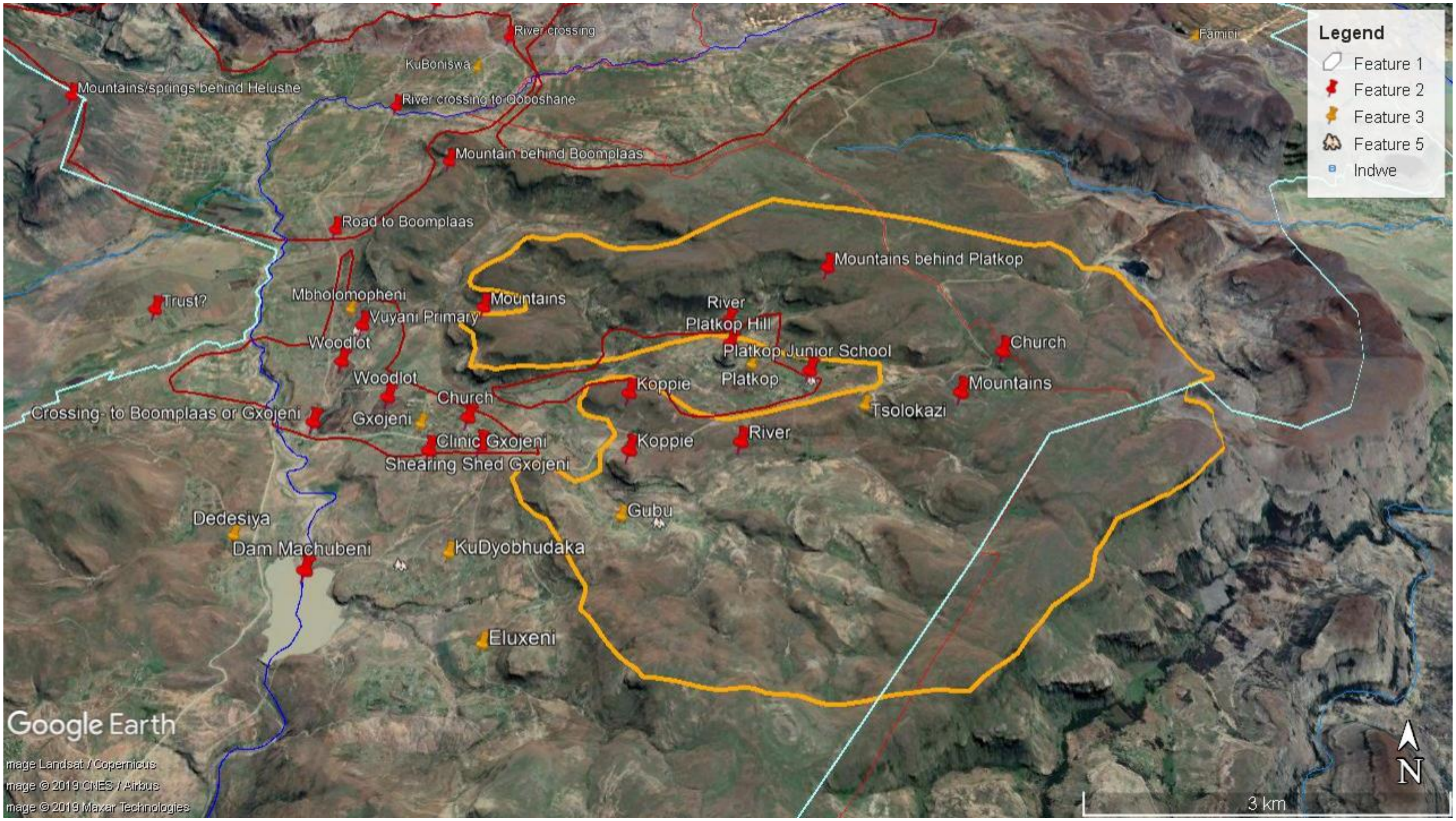

Image 2: Screenshot of the Google Earth base map for WS1 rangelands. Red polygon = Village boundaries; orange polygon = rangeland area.

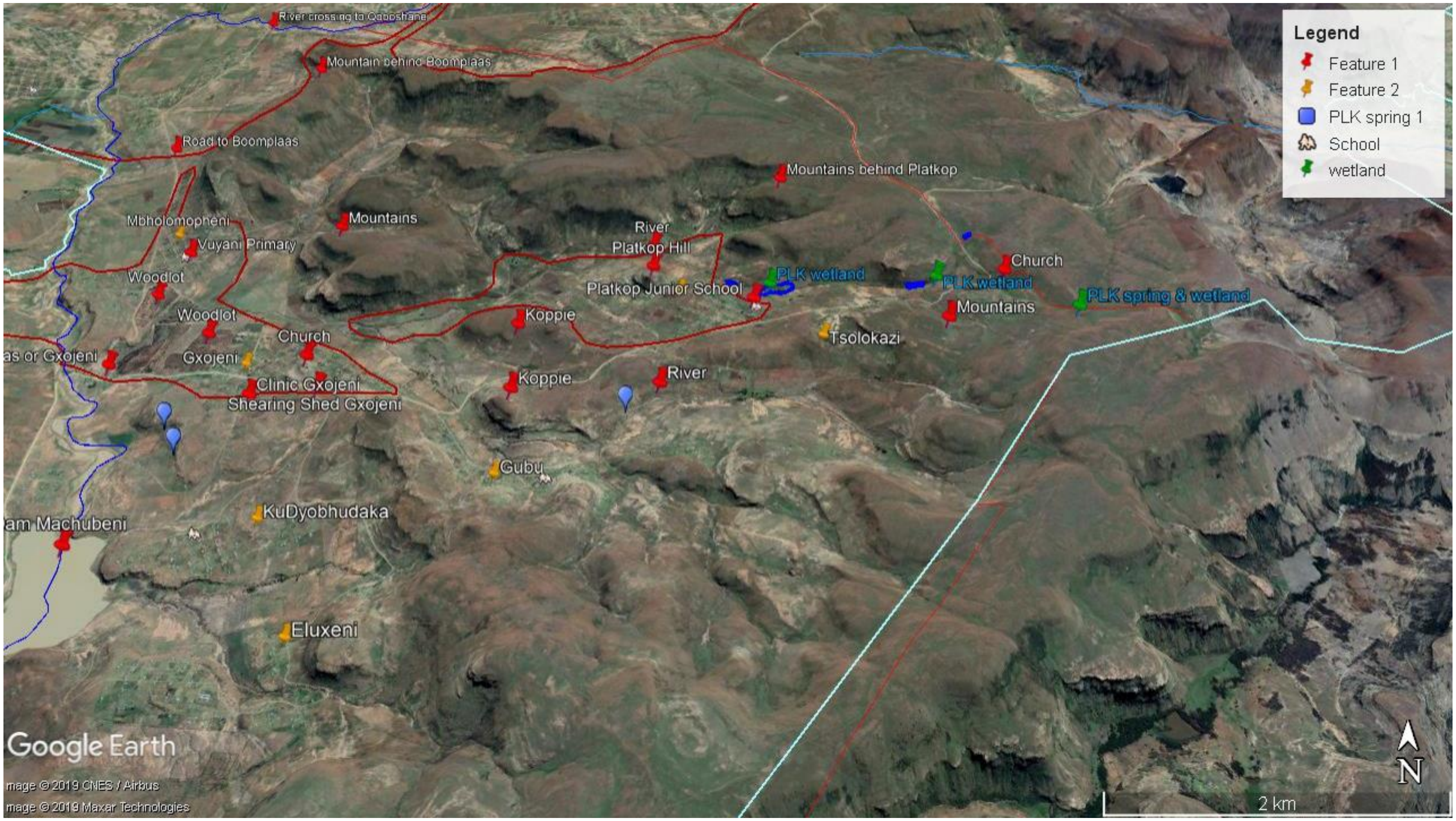

Image 3: Screenshot of the Google Earth base map for WS1 wetlands. Red polygon = Village boundaries.

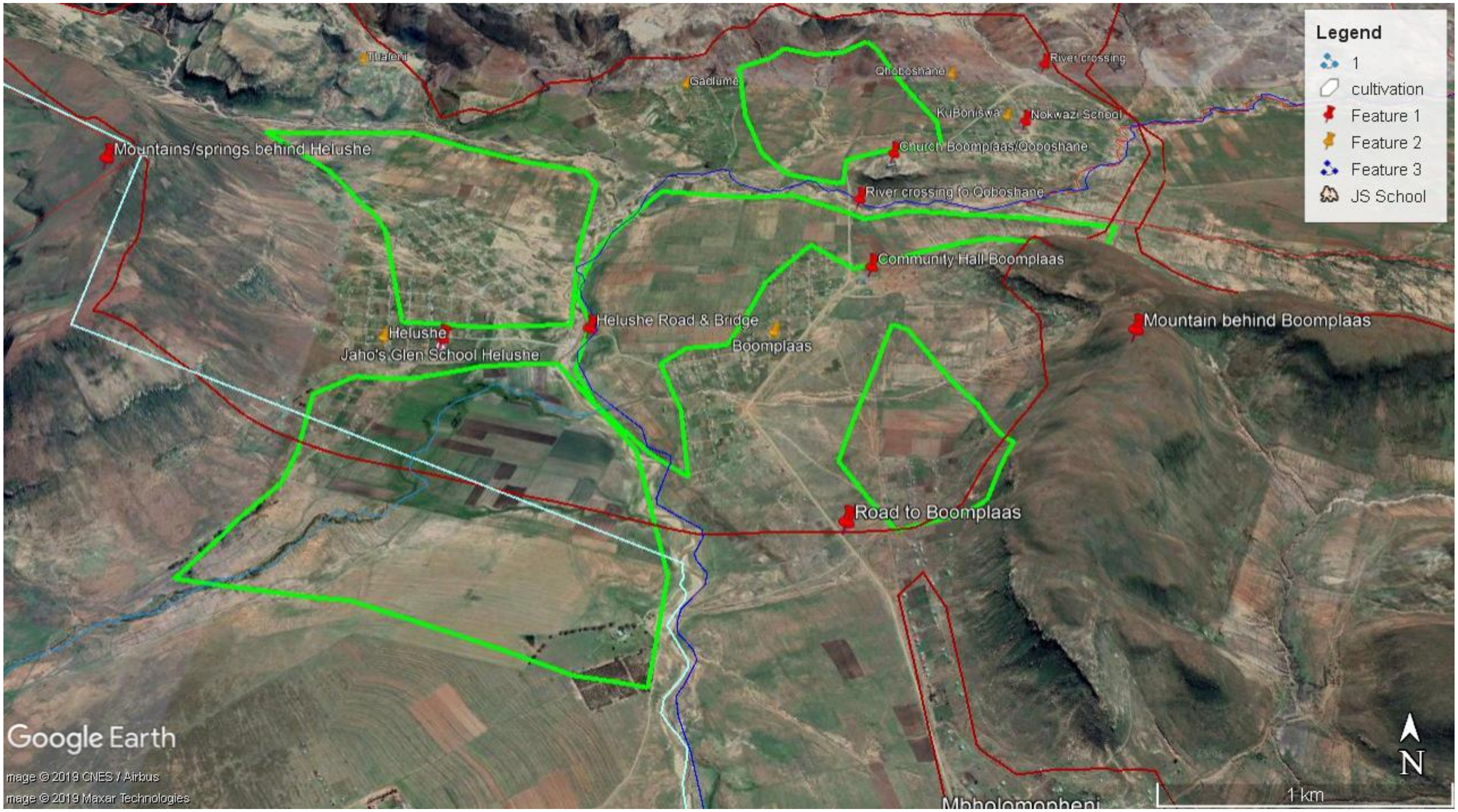

Image 4: Screenshot of the Google Earth base map for WS2 croplands. Red boundary = village boundaries.

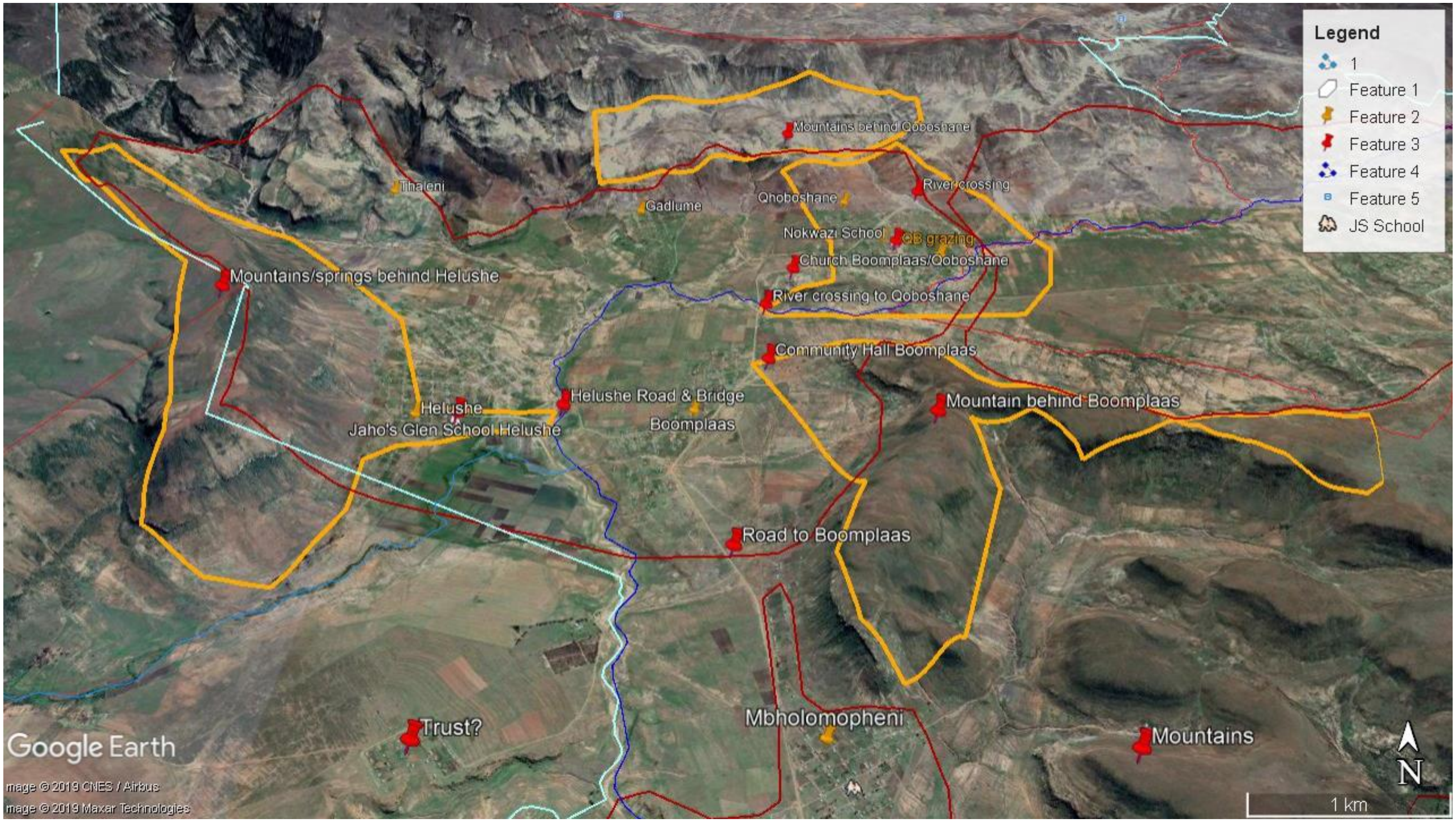

Image 5: Screenshot of the Google Earth base map for WS2 rangeland locations. Red polygon = village boundaries; orange polygon = rangeland area.

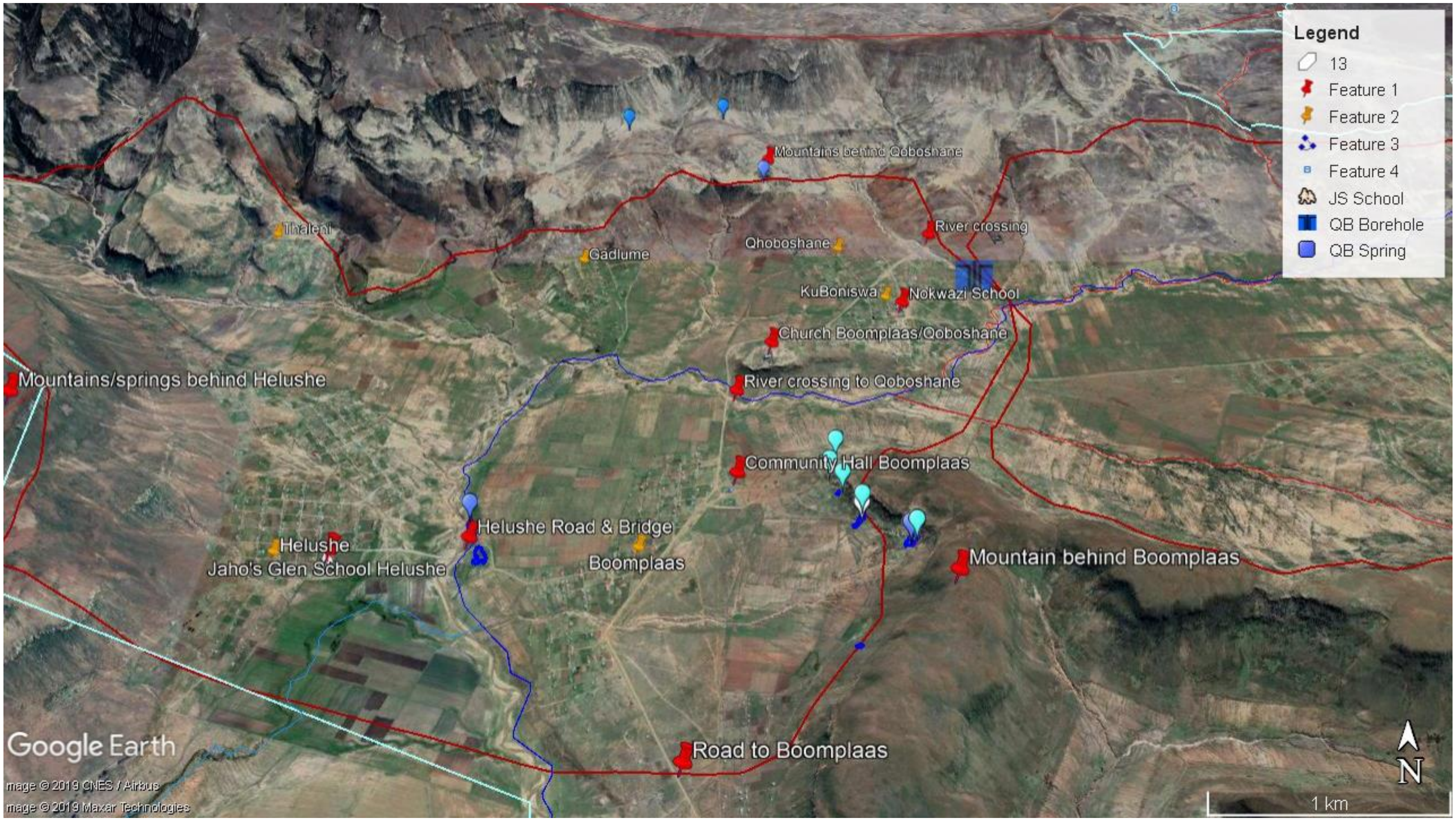

Image 6: Screenshot of the Google Earth base map for WS2 wetland locations. Feature 1 = Village landmarks; Feature 2 = GEF5 villages; and Feature 3 = Cacadu tributary.

Attendance register for May 2019 workshop in Machubeni

21/05/2019 : Key resources meeting
Gxojeni and Platkop

	IGAMA	IFANI	ILALI	SIGNATURE	
1.	Hena	Maseti	Platkop S/S	[signature]	M
2.	Nobuzwe	Nyali	Gxojeni	N Nyali	F
3.	Zumanetize	Soti	Platkop	[signature]	M
4.	Noncedo	Rabe	Phatkop	N. Rabe	F
5.	Sitembele	Madombeni	Gxojeni	(18)	M
6.	Mawaka	Mndini	Gxojeni	[signature]	M
7.	Loyiso	Gongotha	Gxojeni	[signature]	M
8.	Viwe	Hulushe	Gxojeni	[signature]	M
9.	Nonkosis	Noholoza	Gxojeni	[signature]	M
10.	TW Vinjwa	- -	Platkop	TW Vinjwa	M
11.	Bongani	Ntsomi	PLATKOP	B. Ntsomi	M
12.	Badanile	Jamda	PLATKOP	JB	M
13.	Phatho	Jeko	Gxonjeni	[signature]	M
14.	Phathiswa Sinu	Sinuma	Platkop	P. D. Sinuma	F
15.	Zwelethemba	Madywabe	Gxojeni	[signature]	M

12M
3F

9F
+
30

1st 25
15
25
40

24/08/19

Igama	ifani	ilali	signature	Sex
1. Zolile	Silekwa	Qoboshane	[illegible]	M
2.	M.K Ngesi	nKangala		M
3.	NR Velem	Boomplaas	NRVelem	M
4.	N.D. Silekwa	Qoboshane	Nomfusi	F
5.	DM Kandisa	Qoboshane	DMKandisa	M
6.	Silekwa	Qoboshane	N Silekwa	F
7.	XA. MARWANQANA	Qoboshane	[illegible]	M
8.	AM Ndzondza	Qhoboshane	[illegible]	M
9. Nobongile	N. Shenxane	Nkangala	N Shex	F
10. Nosizwe	Thapuko	Boomplaas	N Thapuko	F
11. Nomsingathi	Dywili	Qoboshane	N Dywili	F
12. P.	MKLOSI	Qoboshane	[illegible]	M
13. S.S.	Mayekiso	Qoboshane	SSMayeki	M
14. Cordelia	Vadlule	QOBOSHANE	NCVadlule	F
15. Duzana	Nyanga	Qoboshane	FNyanga	M
16. S Dywili	Dywili	Qoboshane	S Dywili	M
17. NDOYISILE	NYATHELA	BOOMPLAAS	NNyathela	M
18. Y. Madolo	Nelson,	Helushe.	NMadolo	M
19.				M
20.				M
21.				M

18 M

6 F

Informed consent for May 2019 workshop in Machubeni led by Mr Xoxo

Incazelo kunye nemvumelwano

Ndingu Sinetemba Xoxo, umfundi okwizinga eliphakamileyo kwiZiko loPhando ngaManzi kunye neSebe lezeNzululwazi kweZendalo, ndisuka kwiDyunivesiti iRhodes, eMakhanda. Ndenza uphando ngomhlaba yaye ndikhangela ukubaluleka kwawo ekugcineni amanzi. Injongo zolu phando kukuqonda nokuphonononga ukuba indlela yokujonga okusingqungileyo njengenkqubo edibeneyo ingasetyenziswa njani ukuphucula ulawulo lwamanzi emhlabeni ukuze kuphuculwe impilo zabantu ngamaxesha embalela neentlekele. Olu phando luxhaswe ngabeSebe loHlalutyo Ngamanzi, kunye noGEF.

Olu phando luzawkwenziwa ngokohlobo lentlangano yesininzi ezakube imalunga nabantu abangama-30. Le ndibano izakukhokelwa yimibuzo emine ubuncinane, kwaye akulindelekanga ukuba ithathe ngaphaya kweeyure ezimbini. Le ndibano izakusebenzisa imephu ezisephepheni kunye nezo zekhompiyutha. Ukuthatha inxaxheba kwakho kolu phando kuxhomekeke kuwe.

Akukho mingcipheko ozakujonganayo nayo ngokuthatha inxaxheba, kwaye ukuthabatha inxaxheba kungokokuzithandela. Umyinge wegalelo lakho ukuwe kwaye ukuba awuziva ukhululekile unako ukuhamba nanini na. Akukho mpendulo ichanekileyo okanye irongo, ndinomdla kumava nolwazi lwakho. Impendulo zakho zizakushicilelwa ngokubhalwa phantsi, kodwa inkcukacha zakho azizukushicilelwa zona. Iimpendulo zakho zizakubonwa ndim kunye nalowo undongameleyo, kwaye ndizakuzifihla ngobuxhakaxhaka bale mihla ukuqinisekisa ukuba uhlala ufihlakele.

Akukho ntlawulo okanye nzuzo ezakufumaneka xa uthe wathatha inxaxheba, kodwa ukuthatha inxaxheba kwakho kolu phando kubalulekile njengoko kungancedisa ukuba kwakhiwe amaqhinga okugcina umhlaba wenu ukwisimo esibhetele.

Lomsebenzi womganyelwe ngu Gqir. Sukhmani Mantel, uGqi. Jane Tanner no Gqi. Alta De Vos, bonke base Rhodes. Ndizakubhala incwadana endizakuyifaka eRhodes, kukwakho nomnqweno wokupapasha iziphumo kwihlabathi jikelele ngendlela yokufundisa nabanye abantu. Apho inkcukacha zakho zivela khona, azoziphumpo azizukupapashwa. Ndizakubuya malunga nekaTshazimpuzi kunyaka ozayo ndiniphathele ingxelo.

Ukuba unemibuzo ungandibuza ngoku, okanye uqhagamshelane nam kule nombolo: 071 284 9784. Unako ukuqhakamshelana nalowo undongameleyo, uGqi. Sukhmani Mantel kulenombolo 046 603 7965.

Apho sithe sanobugwenxa khona, nceda uqhakamshelane no Rebecca ku 046 603 7005.

Imvume yokuthatha inxaxheba

Ngokuqhubeka uhlale kulendibano usixelela ukuba uyavumelana nokubhalwe ngasentla.

Ingxelo yomcwaningi / umqulu womvume wokufunda umntu

Mna obhalwe phantsi, ndifunde ngokuchanekileyo iphepha lolwazi kubachaphazelekayo ngolwimi abalisebenzisayo. Kwaye ngokusemgangathweni imigudu yenziwe ukuqinisekisa ukuba abathathi-nxaxheba abaye baqonda ukuba oku kungentla kuya kwenziwa. Ndiye ndashiya abathathi-nxaxheba ikopi yemvume enolwazi

: ______ U Tyikitya:Umhla: 2012/5- /êg- Igama: na: SINETEMBA XOXO

Zwelethemba Madyuabe

Ingqina: Umhla: 2019/ Cf ,/-Ä Igama:

Translation in English

I am Sinetemba Xoxo, a Masters degree student from the Institute of Water Research at Rhodes University under the supervision of Dr Sukhmani Mantel, Dr Jane Tanner and Dr Alta De Vos. I am doing research on a recent research area called ecological infrastructure. By definition, ecological infrastructure is any naturally functioning social-ecological system that can deliver ecosystem services as a way of supporting the country's economy. This study is part of an ongoing project with Machubeni, under the GEF5 Sustainable Landscape Management for land management and ecosystem rehabilitation which involves Rhodes University.

In my research study, I am doing research on how an integrated and systems-based approach to land and water resource management and restoration can bring value to water and livelihoods security in times of disaster using Machubeni as one of case study sites. Drought impacts are affecting a lot of people in the Machubeni area, and therefore, I believe that the locals can help us by sharing with sharing about the importance of their natural resources and identify areas they deem to be in urgent need for intervention by means of ecological restoration. I want to uncover knowledge about response strategies and actions needed to protect catchments to maintain or restore their ability to mitigate the impacts of drought. Therefore, you are being invited to take part in this research because you were identified as someone who knows and uses the natural resources at Machubeni. With you knowledge, we will be better equipped to better adapt to climate change impacts.

Procedures

If you agree to be part of this study, you will be asked to partake in a semi-structured interview in a form of group discussion face-to-face with **10-15** other people. This will take around 2 hours of your time. The discussion will be guided by myself, the GEF project interns and the community liaison officers. The questions asked are purely about the natural resources and their importance to your daily life, and are not intended to be sensitive or link directly to personal issues. The workshop will take place in the next two months (sometime between May 1st and May 7th).

For the workshop, a facilitator will ask a prompting question, and everyone will be given a chance to reply. If you do not wish to not answer any of the questions during the workshop, you may do so and we will proceed to the next question. The data will be anonymous, i.e. will not be published in a way that reveals identity, but the processed data will be made available to the public. Notes will be taken during the workshop but your names or identity will not be included in any form. The raw notes and the mapped responses will be saved on a separate cloud folder of which access will be directly limited to myself, the GEF project manager and my supervisors, but the processed data will be made available to the general public. At the conclusion of the GEF project (estimated in 3 years' time), the collected data will be deleted, leaving behind only the processed data.

As a participant, you will also have access to the workshop results once they have been fully processed and integrated to some change analysis results. You will be acknowledged as a group in the final maps and any write up that emerges as a results of this workshop. You will not be receiving any incentives for taking part in this study as participation is only voluntary.

Additional information

This form has been approved by the Rhodes University Ethics Standard Committee**.** If you have any questions, please feel free to contact Sinetemba Xoxo by email at g13x2945@campus.ru.ac.za or by telephone at 046 603 7691.

Alternatively, contact the supervisor, Dr Sukhmani Mantel at 046 603 7695 or s.mantel@ru.ac.za, if you have any questions or concerns about your rights as a research participant.

Consent of subjects

Your proceeding to sit in for this workshop will be taken as consent to be part of this study.

Statement by the researcher/ person reading consent document

I the undersigned, have accurately read out the information sheet to the potential participants in a language understandable to them, and to the best of my ability made sure that the participants that the participants understand that the following will be done:

Sign: ___________________________ Literate witness sign: ____________________________

Date: _________________________ *Date*: ________________________________

APPENDIX 2. PARTICIPATORY GIS METHOD DETAILS FOR TSITSA COMMUNITIES

Report prepared by MSc student Ms Bawinile Mahlaba

Participatory mapping was conducted to obtain stakeholder inputs and prioritise important focal EI natural resources based on community needs. The key natural resources were: wetland, grasslands, abandoned cultivated land and riparian vegetation. Participatory mapping was conducted in two selected villages in the upper catchment of Tsitsa (T35A).

Sigoga and Ntatyaneni villages were selected because of the strong existing research relationship established by ongoing catchment rehabilitation work from the Tsitsa Project at Rhodes University. The Tsitsa Project is funded by the National Department of Environment Forestry and Fisheries to restore the landscape to prevent the silting and, at the same time, ensure sustainability of ecosystems that improve the livelihoods of the people who live there. Tsitsa Project in partnership with Lima Rural Development Foundation (LIMA) organisation working together in the catchment implementing sustainable land use management interventions and plans into the catchment. LIMA is a non-governmental, non-profit organisation, engaged in a broad range of rural and urban development interventions throughout South Africa. The Tsitsa project has established the Community Liaison Officers (CLOs) to link and bridge the gap between people living in the catchment and the Tsitsa project team. The role of CLOs is to connect and exchange communication between communities, Lima and Tsitsa project.

PGIS Method

A participatory Geographic Information System (PGIS) method (a participatory approach, which combines different geo-spatial information management tools and method such as maps and satellite images) was used for participatory planning processes in rural areas and to presents people's knowledge in the form of visual or physical way (Brown and Kyttä, 2014). This method is commonly used in land use planning and management (Brown and Kyttä, 2014). PGIS method was used to allow community members to highlight important types of ecological infrastructure for them, the perceived current state of these ecological infrastructure and to identify their location. In the study, community-based participation was aimed to get community insights on how the focal EI land cover types have changed in terms of degradation state and prioritise focal EI for rehabilitation. The targeted natural resources in the study were wetland or springs, abandoned cultivated lands, riparian vegetation and rangelands. In the process of the participatory workshop, Google Earth and printed digital maps of the area were used to locate the targeted natural resources in the community. Landmark features were used to help the participants locate their area in the maps so that they can point out the important ecological infrastructure for their livelihoods and environment. The priority areas were digitized using Google Earth program.

Recruitment of participants

The community liaison officers working with the Tsitsa project team invited the whole community to the workshop. During the community meeting the sub-headman was asked by the CLO to invite people to attend the workshop. The whole community was invited, and participants were residents in the area who had lived there for a minimum of 10-years and who were above the age of 18 years. Forty people attended the workshop, including the local sub-headman, three CLOs, a representative from Lima and Tsitsa project and four members from Rhodes Research team (Attendance Register at the end of this appendix).

Workshop approach

The first workshop took place on the 19th of November 2019 at Ntatyaneni Primary school and the second workshop was conducted in Sigoga village on 22 November 2019. In both workshop sessions, communities were divided into three randomly selected groups (Figure A1) by workshop facilitators (Rhodes University team, Tsitsa and Lima project representatives). Each group was assigned a CLO and one member of the Rhodes University team to facilitate the workshop. The workshop was facilitated in both English and isiXhosa and the same procedure was used for both workshops. The workshop started with welcome and introductions, explanation of the project aims and objectives, signing of consent document (similar to the one presented in Appendix 1). The ethical approval is attached at the end of this appendix.

Figure A1 Groups for workshops in Sigoga and Ntatyaneni village

Community mapping and presentations

Each group was asked to draw a sketch of (i.e. map out) the catchment, describing how the village looks like focusing on pointing out the location of the areas where the focal EI land cover types are located in the village. Each group was given 40 minutes for drawing and 20 minutes for presentation to the rest of the group (Figure A2).

Figure A2 Sketch maps of location of natural resources presented by the groups

Natural resource prioritisation

The Google Earth image of the area was projected onto the wall where everyone could see it. The facilitators ensured that everyone was able to locate the place where the workshop was held, before proceeding with the prioritisation session. At the end of the mapping exercise all the groups were combined. Three people from the workshop were asked to volunteer to point out on the displayed Google Earth image the location of targeted natural and select the priority resource for rehabilitation in the area sketched from the first exercise. Prioritisation of key important natural resources for rehabilitation based on community needs was done for three targeted natural resources (springs/wetlands, abandoned cultivated land, and grassland/rangelands), excluding riparian vegetation. During this process everyone was welcome to make suggestions and even correct each other (Figure A3).

Figure A3 Images displayed during prioritisation of natural resources in the workshops

For riparian margin, the following question was asked of the participants: “Have you noticed any changes in the size or plant types that are found in the riverbanks over the past 20-year period?” Discussion points were notes and are reflected in the results section. Following the workshop, four community members of Ntatyaneni village were asked to accompany Rhodes University research team for field observation of nearby prioritised resources in the workshop.

Results

Springs and wetlands

Springs are the major source of water in the community because there are no taps found in the area, therefore all springs present in the area are important to communities. At Ntatyaneni village 11 springs were mapped in the area and five springs was ranked as important to the community. In Sigoga village, 12 springs were mapped in the area and 6 springs were identified as important to the community. In both villages, the wetlands or seeps are formed below the springs where water either seeps from the ground or there is constant water flowing from the springs. Wetlands were prioritised for animal use, such as pigs and livestock to get water and good grass for livestock grazing, especially in winter. During site visits that were done at Ntatyaneni village, it was observed that most seeps and springs were connected to gullies/dongas.

Abandoned cultivated land

Abandoned cultivated land in both villages are used for different purposes such as livestock grazing area and cultural practise. At Ntatyaneni village, three abandoned croplands were mapped and only one cropland area was identified to be important to the community. In Sigoga village four abandoned fields were mapped and two of them were identified to be important to the community compared to other cultivated land present in the area.

Rangelands

Rangelands provide food to livestock, for this reason rangelands in both villages are highly important. In Ntatyaneni village one rangeland was mapped and it was ranked to be important. At Sigoga village three rangelands areas were mapped and two rangelands areas were identified as more important compared to the other one.

Riparian vegetation

People noted that there are more *Acacia* (black and silver wattle) alien plants growing in the riparian vegetation and their density is greater than before. In the past people remembered more indigenous plants by the river, such as ‘Umncunube, Udwadwa and Umbhongosi’. Black wattle is being used by the villagers for firewood and building material.

Ethical approval letter from Rhodes University

RHODES UNIVERSITY
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Human Ethics subcommittee
Rhodes University Ethical Standards Committee
PO Box 94, Grahamstown, 6140, South Africa
t: +27 (0) 46 603 3055
f: +27 (0) 46 603 8822
e: ethics-committee@ru.ac.za

www.ru.ac.za/research/research/ethics
NHREC Registration no. REC-241114-045

27 November 2019

Bawinile Mahlaba

Review Reference: 2019-0663-929

Email: g18m1959@campus.ru.ac.za

Dear Bawinile Mahlaba

Re: Assessment of ecological infrastructure in Tsitsa River catchment

Principal Investigator: Dr. Sukhmani Mantel

Collaborators: Ms. Bawinile Mahlaba

This letter confirms that the above research proposal has been reviewed and **APPROVED** by the Rhodes University Ethical Standards Committee (RUESC) – Human Ethics (HE) sub-committee.

Approval has been granted for 1 year. An annual progress report will be required in order to renew approval for an additional period. You will receive an email notifying when the annual report is due.

Please ensure that the ethical standards committee is notified should any substantive change(s) be made, for whatever reason, during the research process. This includes changes in investigators. Please also ensure that a brief report is submitted to the ethics committee on the completion of the research. The purpose of this report is to indicate whether the research was conducted successfully, if any aspects could not be completed, or if any problems arose that the ethical standards committee should be aware of. If a thesis or dissertation arising from this research is submitted to the library's electronic theses and dissertations (ETD) repository, please notify the committee of the date of submission and/or any reference or cataloging number allocated. Sincerely

Prof Joanna Dames

Chair: Human Ethics sub-committee, RUESC- HE

Attendance register for November 2019 workshops in Tsitsa: Ntatyaneni Village

Attendance Register

TSITSA PROJECT | environmental affairs — Department: Environmental Affairs, REPUBLIC OF SOUTH AFRICA | RHODES UNIVERSITY Where leaders learn | LIMA

Meeting: Learning Words & Community map. day 1

Date: 18/11/2019

Place: Ntatyaneni Junior school (Hlankomo)

Name	Village	Contact details (PHONE OR EMAIL)	Signature
CHRIS Matsoso	Skansin	073600 2405	[illegible]
Bulelwa mpondo	Katkop-Esigcwebeni	0782125766	[illegible]
LUYANDA MATHOLE	HLANKOMO Entatyaneni Enkulu	0618514800	[illegible]
Maingwane S.	Hlankomo	0783326747	
Mzukisi Masiso	Nos, Hlankomo	0785893 605	[illegible]
Dumisani Zitha	NTATyaneni Enkulu	0734708613	[illegible]
M Xekethwana	NTaTyaneni	0818169629	
Swora Mathole	Ntatyoni	0834654002	
Sindilizwe	MAHlati	0630496583	
M	matHoLe		
Masphelo	Gojana	0719734399	
x		0640407312	
N-	MATode	0767602054	
A. Mathole	MATHOLE	0663389186	A. Matholer
T. Nyoka	NYOKA		[illegible] x

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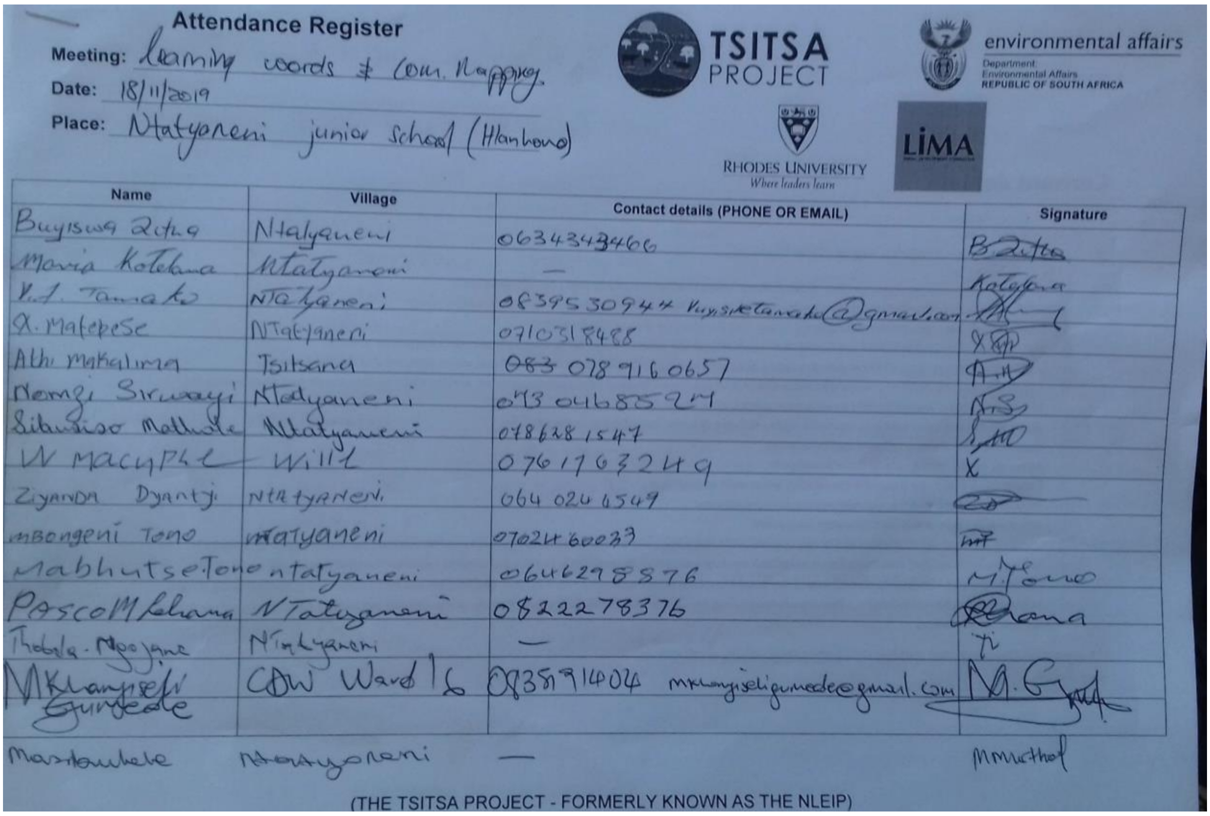

Attendance Register

TSITSA PROJECT | environmental affairs — Department: Environmental Affairs, REPUBLIC OF SOUTH AFRICA | RHODES UNIVERSITY Where leaders learn | LIMA

Meeting: Learning words & com. Mapping.

Date: 18/11/2019

Place: Ntatyaneni junior school (Hlankomo)

Name	Village	Contact details (PHONE OR EMAIL)	Signature
Buyiswa Qitha	Ntatyaneni	0634343466	B Qitha
Mavis Kotelana	Ntatyaneni	—	Kotelana
V.T. Tamako	NTatyaneni	0839530944 Vuyisiletamako@gmail.com	[illegible]
A. Matebese	NTatyaneni	0710318488	[illegible]
Athi Makalima	Tsitsana	~~083~~ 078 916 0657	[illegible]
Nomzi Sirwayi	Ntatyaneni	073 0468524	[illegible]
Sibusiso Mathole	Ntatyaneni	078628 1547	[illegible]
W Macuphe	Will	0761763249	X
Ziyanda Dyantyi	NtaTyaneni	064 024 6549	[illegible]
mbongeni Tono	Ntatyaneni	0702460033	[illegible]
Mabhutse Tono	ntatyaneni	0646298876	M Tono
Pascol Mkhana	NTatyaneni	0822278376	[illegible]
Thobile Mgojane	Ntatyaneni	—	[illegible]
Mkhanyiseli Gumede	CDW Ward 16	0838914404 mkhanyiseligumede@gmail.com	M. G[illegible]
Masibulele	Ntatyaneni	—	Mmathol

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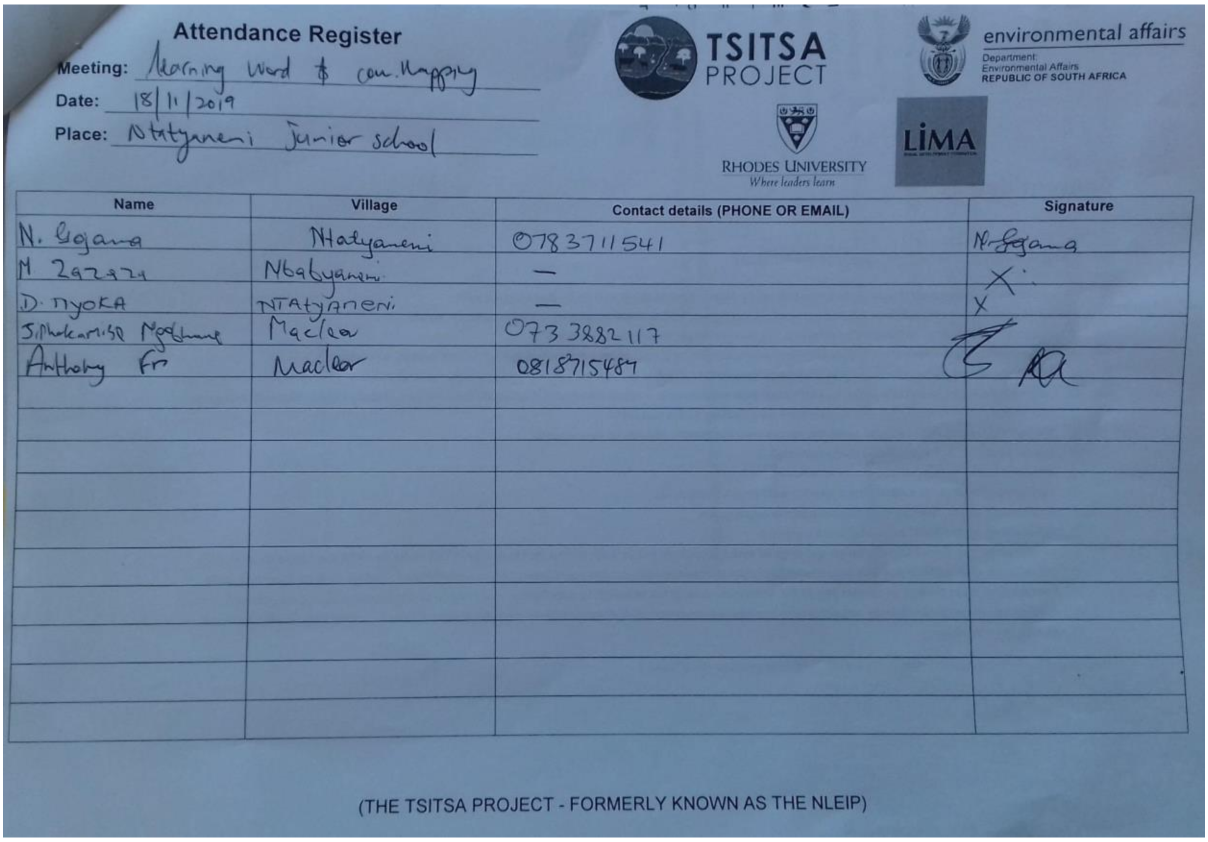

Attendance Register

Meeting: Learning Word & con. Mapping

Date: 18/11/2019

Place: Ntatyaneni Junior school

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Name	Village	Contact details (PHONE OR EMAIL)	Signature
N. Gqana	Ntatyaneni	0783711541	N. Gqana
M Zazazi	Ntatyaneni	—	X
D. Nyoka	Ntatyaneni	—	X
Siphokamisa Mgxhwane	Maclear	0733882117	
Anthony Fr	Maclear	0818715487	

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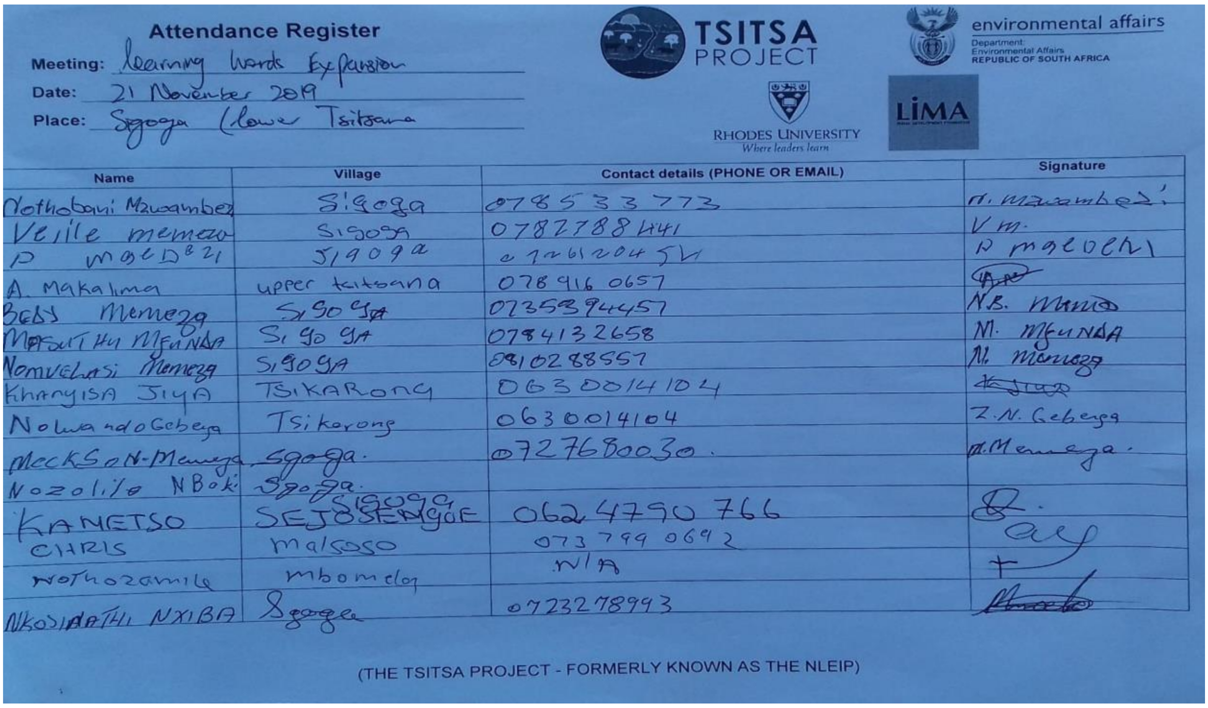
Attendance register for November 2019 workshops in Tsitsa: Sigoga Village



Attendance Register

Meeting: Learning Words Expansion

Date: 21 November 2019

Place: Sigoga (lower Tsitsana

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Name	Village	Contact details (PHONE OR EMAIL)	Signature
Nothobani Mzwambe	Sigoga	078 533 773	N. Mzwambe
Velile memeza	Sigoga	0782788441	V.m.
P maqedezi	Sigoga	0726120454	P maqeden
A. Makalima	upper tsitsana	078 916 0657	
Beky Memeza	Sigoga	0735394457	N.B. Mano
Mfusi Mfunda	Sigoga	0784132658	M. Mfunda
Nomvelisi Memeza	Sigoga	0810288557	N. Memeza
Khanyisa Jiya	Tsikarong	0630014104	
Nolwandl Gebeza	Tsikarong	0630014104	Z.N. Gebeza
Meckson Memeza	Sigoga.	0727680030.	M.Memeza.
Nozolile NBoki	Sigoga.		
Kanetso	Sigoga Sejosenyane	0624790766	
Chris	malsoso	073 799 0692	
Nothozamile	mbomelo	N/A	+
Nkosinathi Nxiba	Sigoga	0723278993	

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Attendance Register

TSITSA PROJECT
environmental affairs
Department: Environmental Affairs
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Meeting: LW & inst
Date: 21 November 2019
Place: Sigoga

Name	Village	Contact details (PHONE OR EMAIL)	Signature
N. August	Sigoga	063 872 1993	N. August
N. ngxinto	ematugulu	0788697568	[illegible]
N. Duna	Sigoga	0730672495	N.Duna
N. Siqwinta	Sigoga	063 ~~796 46~~ 791 0385	
M Sejosengoe	Sigoga	0738020768	[illegible]
N. Memeza	Sigoga	–	nobamzimea
Nogcinumzi Nxeba	Sigoge	–	X
Nolasti Rhum	Sigoga	0721300178	X
Buyekhaya Tanishe	Sigoga	0718373278	B.Tanishe
Vukile Memeza	Sigoga		[illegible]
Ntombikayise Konto	Khohlomoriti	0729576530 / ntombikayisekonto@gmail.com	NKonto
N. Mgedezi	Sigoga	0729466566	N.Mgedezi
N. C. Duna	Sigogo	0835065170	[illegible]
T E Duna	Sigoga	078398 9857	[illegible]
L. Bhewuza	Upper tsitsana		[illegible]
Anthony Fry	Maclear (Rhodes)	0818715487 -	[illegible]

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Attendance Register

TSITSA PROJECT
environmental affairs
Department: Environmental Affairs
REPUBLIC OF SOUTH AFRICA
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Meeting: learning words & institutions
Date: 21 November 2019
Place: Sigoga Village (lower Tsitsana)

Name	Village	Contact details (PHONE OR EMAIL)	Signature
Nozasasa	Sigoga	0782468345	N April
Nomakethini	Sigoga		N. mbegana
Nolosi mbosigana	Sigoga		N Mbosigan
Nombuso Memeza	Sigoga	081 0954060	N. Memeza
Sinitemba Xoxo	R.U	sinetemba.xoxo@gmail.com	[illegible]
Georgina	Sigoga	—	[illegible]
Cisers	Malsosa	073 799 0692	[illegible]
Siphokazi Ngqathane	Maclear (Lima)	073 3882 117	[illegible]
Bawinile Mahlaba	Grahamstown	078 6161 605	[illegible]

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