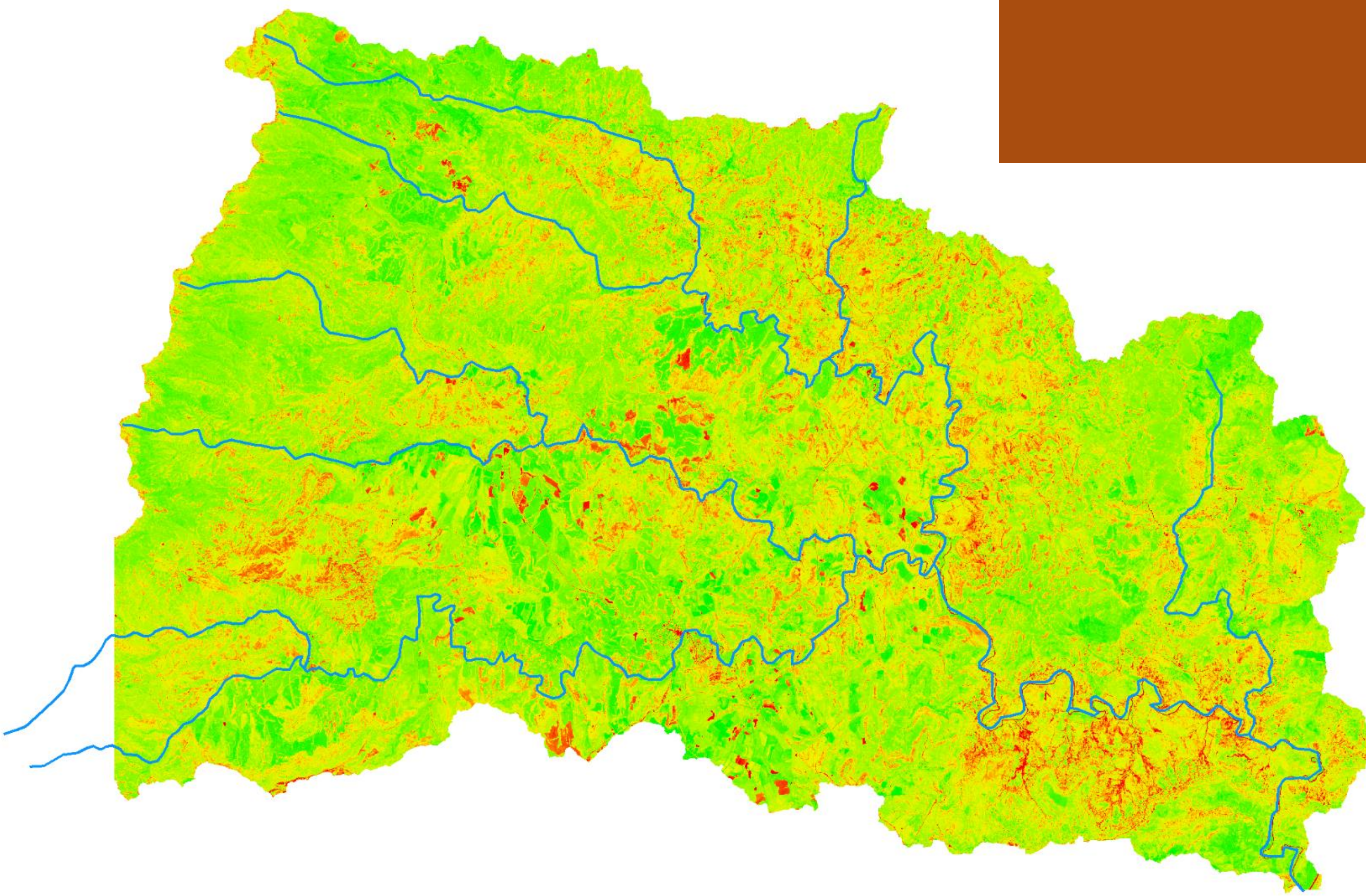
BIOPHYSICAL MONITORING: REPORT 2 OF THE UPPER TSITSA RIVER CATCHMENT (T35 A-E) WITH UPDATES ON THE SDG 15.3.1 INIDICATOR

TSITSA PROJECT



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TSITSA PROJECT

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EXECUTIVE SUMMARY

The Tsitsa Project strives to restore functional landscapes to the benefit of local and downstream users. It prioritises its limited resources for the maintenance of functioning, but threatened, ecological infrastructure overly severely degraded systems in order to avoid further degradation while supporting local livelihood diversification.

The Tsitsa Project is currently engaging with sustainable land management and restoration work in Quaternary Catchment T35 A-E. This targets the upper Tsitsa River catchment and is the current focus area for the biophysical monitoring. In order to gain an understanding of the physical processes at play in the Catchment and the success of different rehabilitation processes it is imperative to conduct biophysical baseline and monitoring surveys to guide effective and strategic adaptive management.

This report follows on the Biophysical Monitoring Plan (Schlegel *et al.,* 2019), Biophysical Monitoring Methods (Huchzermeyer *et al.,* 2019a) and Biophysical Monitoring Report 1 (Huchzermeyer *et al.,* 2019b) set out by the Tsitsa Project. This report briefly covers the findings of the previous biomonitoring reports followed by a look at the indicators that have been identified as being key for the Tsitsa Project and their respective monitoring protocols. Lastly, the Tsitsa Catchment is described according to the three sub-indicators of the Sustainable Development Goals indicator 15.3.1 (proportion of land that is degraded over total land area).

Biophysical monitoring report 1 for the upper Tsitsa Catchment

Huchzermeyer *et al.* (2019a) set out the methods for the biophysical monitoring done to date for the Tsitsa Project and includes details on monitoring sites and the methodology for data collection.

Huchzermeyer *et al.* (2019b) report on the main results of the biophysical monitoring done to date (2019) for the Tsitsa Project which includes rainfall, water quality and quantity, river, wetland and veld condition in Catchment T35 A-E. The key findings are given below. From 11 rain gauges scattered across the catchment, rainfall volume, event magnitude, intensity, duration and extent are measured (2015-2019). Rainfall at monitoring sites higher up in the catchment receive annual rainfall of greater than 700 mm/year (T35 A, B, C, F). Sites in the lower and middle catchment receive rainfall between 500-600 mm/year (T35 D, E, G, H, J, K). The highest intensity rainfall events are found in the North-western part of the catchment. Maximum 5 minute rainfall events at Catchment T35 A, B & D exceeded 13 mm/5 minutes (156 mm/hour), which is high on a global scale. Catchment C, E & G exceeded 10 mm/5 minutes (120 mm/hour) and Catchment F, H, J & K exceeded 6 mm/5 minutes (72 mm/hour).

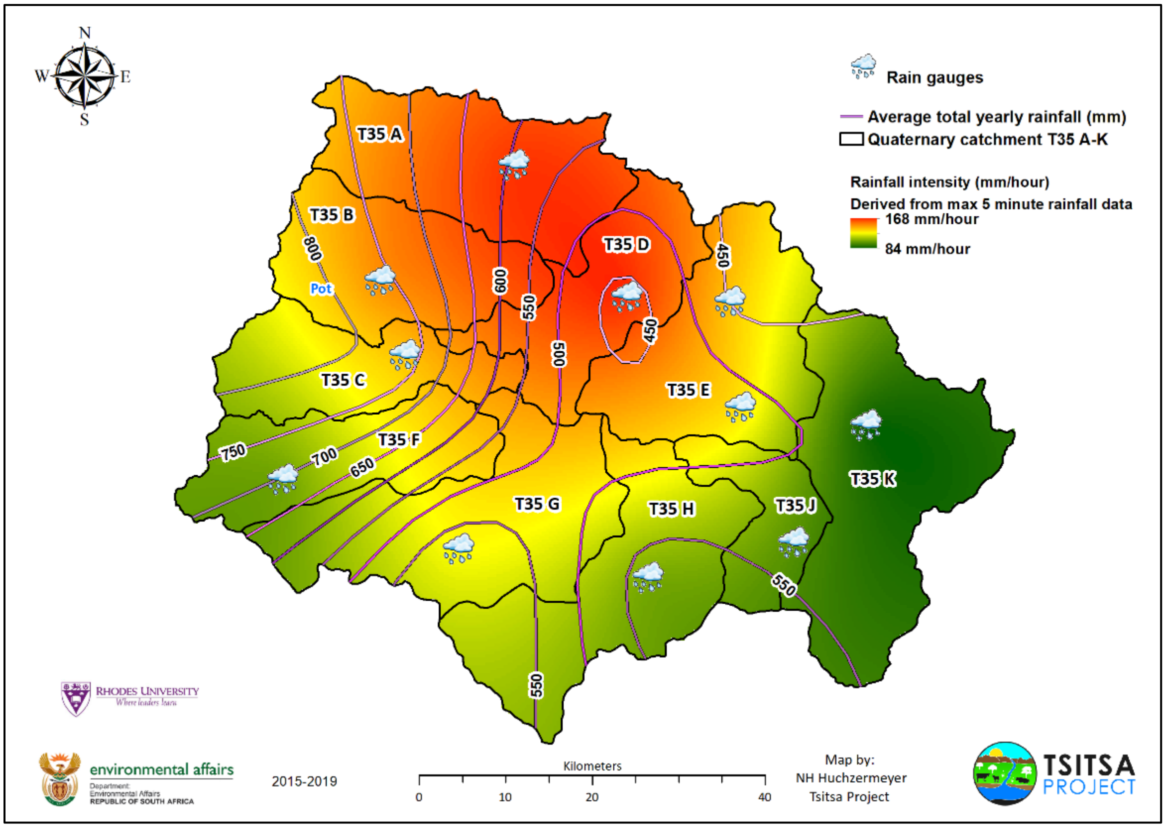

FIGURE 1: RAINFALL TRENDS IN THE GREATER TSITSA CATCHMENT (2015-2019)

There are currently 11 river monitoring sites at which a combination of hydrology, water quality and geomorphic (habitat) condition are being monitored. Months with little or no rainfall generally have low discharge values (dry season baseflows). Discharge peaked during summer months due to heavy rains in the catchment (wet season baseflows and surface runoff). Local rainfall events can increase the discharge significantly, particularly at the start of the rainy seasons. Snowmelts (e.g. August 2016) can also cause spikes in discharge during the winter months. Peak discharges at the start of the monitoring period (2016) were well below average but have been rising with increased rainfall in the catchment in subsequent summer months. The peak discharge at T3H006 (Tsitsa at the N2 near Qumbu) in 2019 exceeded the 10 year flood indicating very high discharges for the season despite the general drought conditions.

Overall the water quality indicated a balanced system with the exception of increased phosphate levels and turbidity and the reduction in clarity due to high suspended sediment concentrations in flood waters. This indicates widespread soil erosion and inputs of phosphates from sewage works and agricultural fields. The SASSv5 scores are reported for each monitoring sites for April/May 2019 and give an indication of the ecological condition of the river at the monitoring site and the river upstream of the site. The ASPT score for April/May 2019 ranged from 4.9 - 7.5 across all the monitoring sites indicating ecological conditions ranging from very poor to good. A reduction in the ASPT scores and ecological conditions at each site can be attributed to the lack of habitat (mostly due to the embeddedness of coarse substrates) at these sites (due to erosional catchment processes and bed gradient) and high flows with turbid waters experienced during the monitoring survey.

Terrestrial baseline surveys and monitoring are being conducted at a catchment scale. Land cover/use, landscape connectivity and ecosystems have been mapped using a combination of medium-resolution satellite imagery, higher-resolution aerial imagery and field verification (Huchzermeyer *et al*., 2018a; Huchzermeyer, *et al*., 2018b & Schlegel *et al*., 2018). A base-line map, classifying land cover at a catchment-scale, of the catchment was generated. Mapping of these ecosystem components will be mapped on a ≥ 5 yearly interval. Snyman (2019) used Landsat imagery to extract burn scars for Catchment T35 A-E from 1984 to 2018. Preliminary findings found that there was a decrease in the area of fire scars over the past 30 years, fire scars are larger, fire frequency and intensity is higher in the upper catchment (private land) compared to the middle and lower catchment (traditional councils).

To assess the current veld condition, 8 veld monitoring sites were chosen that represent different land-use areas, geology, elevations and vegetation types. Results include dominant grass species, biomass, veld condition and grazing capacity. Sites classified as having a very poor veld condition occur on abandoned cultivated lands were the soil structure has been previously disturbed and not given enough time to recover. These sites are heavily utilized and have low biomass values (< 1 000 kg.ha^{-1}) and only poor grazing grass species are present with large areas of bare ground. These sites are also located on the mudstones of the Elliot and Molteno geological formation. These mudstones are highly erodible particularly when the vegetation cover is inhibited. Sites classified as having a poor veld condition are heavily grazed with biomass ranging from 1 000-2 000 kg.ha^{-1}. Sites with moderate veld condition were located in a managed grazing camp and on a valley bottom close to a wetland. Biomass ranged from 1 600-2700 kg.ha^{-1} and good grass cover and minimal bare ground was evident. All the sites would benefit by prolonged rest periods to allow for the stabilization of grass and other important plant population through re-growth and full seed production.

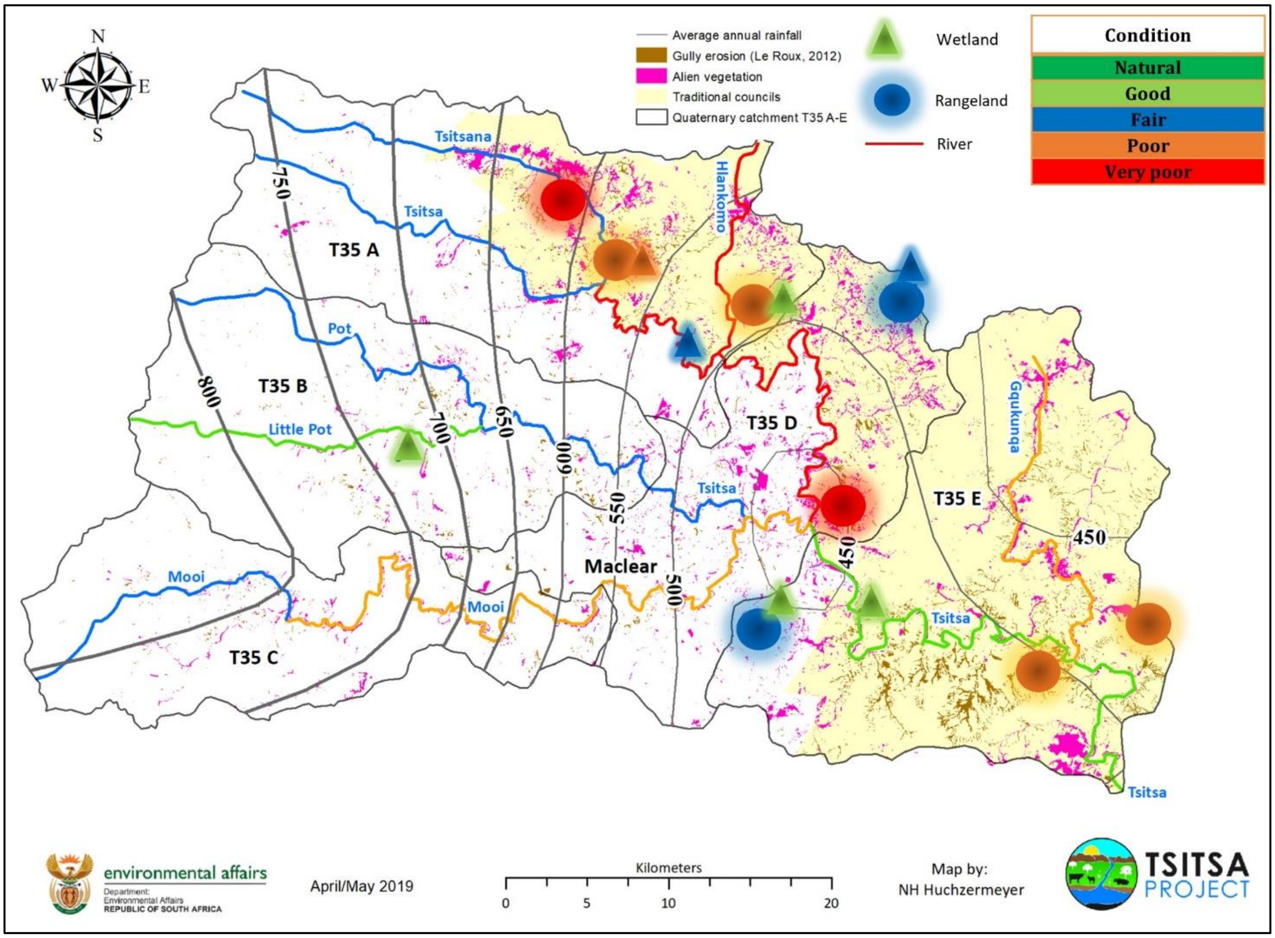

FIGURE 2: CURRENT CONDITION OF THE UPPER TSITSA CATCHMENT

Over 2 800 wetlands were identified covering a total area of over 7 600 ha, ranging from larger valley bottom wetlands to smaller hillslope seep wetlands (Schlegel *et al.,* 2018). A range of wetlands (7 sites) were chosen to investigate their current condition, species composition and look at their effectiveness as sediment buffers in the landscape at a course scale. Most of the investigated wetlands were found to be in a good to fair condition and are acting as important sediment sinks in the respective landscapes.

Indigenous vegetation (both forests and other smaller woody species) are important biodiversity hot spots that also provide a variety of building materials and are important for cultural (fighting sticks and bark for medicine) and spiritual values (Geldenhuys *et al.,* 2016; Ngwenya, 2016). There are a total of 4 243 patches in Catchment T35 A-E dominated by indigenous plants, with a total area of 3 985 ha (this excludes patches of vegetation that have indigenous plants but are dominated by alien vegetation). Of this 466 (1 575 ha) were identified as Indigenous Forest patches and 3 777 (2 410 ha) patches were identified as other indigenous vegetation (small trees, shrubs and bushes).

A total of 37 dominant alien woody species were identified in Catchment T35 A-E of which 7 species (silver wattle, black wattle, green wattle, poplar, eucalyptus, pine and Mauritius thorn) are invading hillslopes, riparian zones and indigenous vegetation on a large scale. Approximately 51% of the area covered by alien woody vegetation occurs on hillslopes, 43% in the riparian zones and the remaining 6% are spreading from drainage lines, plantations, gardens and woodlots. 56% of the alien vegetation category was verified in the field. From the alien vegetation category verified in the field only 3% was noted to be actively used and harvested to such an extent that it was no longer spreading. This is particularly evident within close walking distance of villages.

Key indicator monitoring protocols

Indicator protocols for 6 biophysical indicators that were identified as essential for the Tsitsa Project were identified by the biophysical monitoring and PMERL group. These indicators are:

1. River health
2. Baseflow monitoring
3. Grassland condition
4. Landscape function
5. Woody invasive species cover
6. Suspended sediment concentration

These protocols are presented in a standardized format (with the help of the PMERL group) which includes the type of indicator, why, what, where and how it is measured (see Section 5). In addition some key results of the indicators or indicator tests are given from results reported in Huchzermeyer *et al.* (2019b).

Sustainable development goals (Indicator 15.3.1)

“The Sustainable Development Goals (SDGs) are the blueprint to achieve a better and more sustainable future for all. They address global challenges including poverty, inequality, climate change, environmental degradation, peace and justice. There are 17 interconnected goals which should be achieved by 2030” United Nations (2019). Goal 15 is the most relevant to the biophysical monitoring and the sustainable land management work done by the Tsitsa Project can contribute to the aspects that the indicators track over time. Target 15.3 aims to combat desertification, restore degraded land and soil, including land affected by desertification, droughts and floods, and strive to achieve a land degradation-neutral world by 2030. Indicator 15.3.1 looks at the proportion of land that is degraded over the total land area. By assessing trends in land cover, land productivity & carbon stocks in Catchment T35 A-E we can find out what the condition of the catchment is according to international goals and standards. This also gives us the opportunity to comment on these coarse global indicators based on our higher resolution monitoring and landscape understanding.

Trends.Earth is a product of the Land Degradation Monitoring Project in partnership with Conservation International, Lund University, and the National Aeronautics and Space Administration (NASA), and is funded by the Global Environment Facility. It uses global data sources to assess and monitor land degradation at several scales and can be used to track achievement of the sustainable development goals (Trends.Earth, 2019). Trends.Earth computes the three sub-indicators (productivity, land cover and SOC) from Indicator 15.3.1 and integrates the results following the **one-out all-out** rule to come up with total land area that is degraded.

Details of the South African national **land cover** datasets are given in this report and changes in land cover between 1990 and 2018 are discussed. Land cover change assessments have been set up by Geoterraimage SA (Thompson, 2019). The largest changes occurred to the grasslands due to an increase in planted forests/plantations. Other noteworthy changes of grasslands is into natural wooded land and thicket/dense bush (most likely alien vegetation or indigenous bush encroachment) and into eroded and barren land. Loss of grasslands to eroded lands is particularly evident in the lower catchment (T35 E). A positive change (possibly due to better mapping accuracy) is a change of grassland into wetlands. According to Trends.Earth 13% of the total land area in Catchment T35 A-E 12% of the land cover has improved, 70% has remained the same and 18% has changed to a degraded state (1990-2018).

Land productivity is defined by the total above-ground net primary production (NPP). The annual NPP in Catchment T35 A-E fluctuates from year to year and the general trends can most likely be correlated with average yearly rainfall in the catchment (this needs to be confirmed after a historical rainfall analysis is conducted). However, there are clear trends of areas that have higher NPP such as forested and plantation areas and areas with much lower NPP such as degraded valley bottom areas in the lower catchment. Trends in rangeland performance and forage production over the past two decades were evaluated at five grassland sites by Biotrack (2019) in Catchment T35 A-E. Biotrack (2019) found that the spatial distribution of grass productivity classes across the sub-catchments has a clear trend of areas with high values in a north-south direction through the centre of the catchment which receives high rainfall and contains commercial farms. Low values occur predominately in the north-eastern and south-eastern corners of the lower catchment which exhibits large areas of land degradation. Of the five study sites, productivity is consistently higher in remote, ostensibly relatively intact grasslands in the upper catchment areas, with lowest production values detected in association with abandoned cultivated lands in communal areas. This differs significantly from the SDG indicator that shows the opposite, high productivity in the lower catchment and low productivity in the upper catchment. According to Trends.Earth 13% of the total land area in Catchment T35 A-E has improved in productivity, 49% of the land area has remained stable and 38% has declined in productivity and can be classified as degraded in terms of productivity (2001-2015).

Carbon stock as defined by the United Nations (2019) is the quantity of carbon stored in an area which has the capacity to either accumulate or release carbon. Carbon stocks comprise of above and below ground biomass, dead organic matter and soil organic carbon. Soil Organic Carbon (SOC) was adopted as the metric for carbon stocks as they are less impacted by seasonal changes in standing biomass (grazing and fire can alter these rapidly). SOC levels in the Tsitsa Catchment are highest in the higher altitude grasslands as well as in the presence of woody vegetation. The eroded areas, particularly in the river valleys where large areas of the land have been cultivated and left bare, exhibit very low levels of SOC. The SOC levels can be increased by practising sustainable soil management. According to

Trends.Earth 13% of the total land area in Catchment T35 A-E approximately 6% of the land area (1990-2018) has seen an improvement in SOC, 87% has remained stable and 7% has seen a reduction in SOC (degraded).

After combining the three indicators in Trends.Earth only 14% of the total land areas shows an improvement, 51% of the land area remains stable and a staggering 36% is degraded. However, the degradation within the catchment is still linked closely to the loss of grasslands as well as the low productivity rates, from remotely-sensed vegetation indices, in parts of the grasslands. By targeting these two aspects the land in Catchment T35 A-E can be improved drastically.

Concluding remarks

A recent review by Prince (2019) details the challenges that arise when using remote sensing for the Sustainable Development Goal (SDG 15.3.1) productivity indicator. The challenges that are highlighted include that remotely sensed vegetation data on their own are inadequate to classify or monitor land degradation and the lack of development in understanding the physiological and ecological characteristics of different plant functional groups and how they reflect on remotely sensed vegetation indices. Prince (2019) also points out the need to understand how different ecological processes transform the available NPP to valuable goods and services. Prince (2019) stresses the importance of having baselines and reference conditions that specify the productivity of certain land areas in the absence of anthropogenic causes of land degradation. Therefore, Prince (2019) concludes that the use of vegetation-indices to remotely-sense degradation is not adequate for interpreting the SDG 15.3.1 productivity indicator.

This could explain the high level of 'degradation' displayed in Catchment T35 A-E (and the rest of SA) when using remote sensing techniques such as Trends.Earth to establish land productivity. It is important to note that these methods are designed for a very course (global) scale and when zoomed into a catchment scale the results are either both variable between different methods (e.g. BioTrack, 2019 & Trends.Earth) and do not accurately reflect was is actually happening on the ground when compared to finer scale data. Therefore, the current work that the Tsitsa Project has done to build baseline data at a catchment and site scale is very important to monitor changes in degradation. It is imperative to continue with the biophysical monitoring on the ground to help supplement the remotely sensed data.

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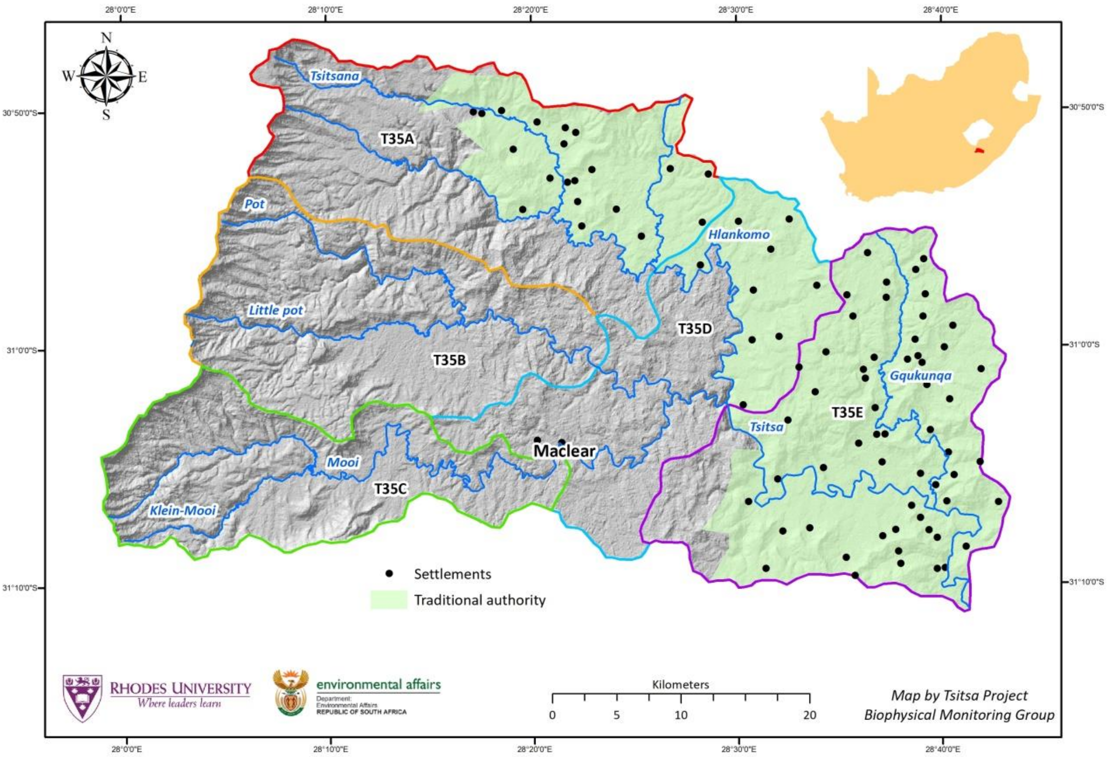
LIST OF ABBREVIATONS

ASPT	Average Score Per Taxa
AVHRR	Advanced Very-High-Resolution Radiometer
DEFF	Department of Environment, Forestry & Fisheries
DWS	Department of Water & Sanitation
DO	Dissolved Oxygen
EC	Electrical Conductivity
EFlows	Environmental Flows
FAO	Food and Agricultural Organisation
GIS	Geographical Information Services
IAP	Invasive Alien Plant
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resources Management
LAI	Leaf Area Index
LFA	Landscape Function Analysis
LSU	Livestock Unit
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	The National Aeronautics and Space Administration

NDVI	Normalized Difference Vegetation Index
NPP	Net Primary Production
PMERL	Participatory Monitoring, Evaluation Reflection & Learning
PSN	Net Photosynthesis
PsnNet	Net Photosynthetic activity
SANBI	South African National Biodiversity Institute
SASSv5	South African Scoring System Version 5
SDG	Sustainable Development Goals
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
TP	Tsitsa Project
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
USGS	United States Geological Survey
VIIRS	Visible Infrared Imaging Radiometer Suite

1. UPPER TSITSA RIVER CATCHMENT AT A GLANCE



The upper Tsitsa River Catchment (T35 A-E) is in the Eastern Cape province of South Africa. The catchment receives summer rainfall and is characterised by steep topography, with the prominent Drakensburg Escarpment forming the headwaters, followed by a second smaller escarpment in the lower catchment. Soils become increasingly more erodible as you move down the catchment, evidenced by the formation of large gullies.

AREA

~200 000 ha
(Catchments T35 A-E)

POPULATION

~45 000 Residents

MAIN LAND COVER/ USE for 2018

69% Grasslands

9% Cultivation

9% Plantations

6% Natural wooded land/thicket/forest

4% Built-up

2% Wetlands

1% Other

INTERVENTION AREA

~76 000 ha Traditional councils

~124 000 ha Private land

2. BIOPHYSICAL MONITORING IN THE UPPER TSITSA CATCHMENT (SCHLEGEL *ET AL.*, 2019)

The Tsitsa Project strives to restore functional landscapes to the benefits of local and downstream users. It prioritises its limited resources for the maintenance of functioning, but threatened, ecological infrastructure over severely degraded systems. The Tsitsa Project is currently doing restoration work in Quaternary Catchment T35 A-E. This targets the upper Tsitsa River catchment and is the current focus area for the biophysical monitoring. The aim is to better understand the physical processes at play under different land use scenarios currently existing in the landscape and those introduced by restoration and management efforts in order to guide effective restoration.

2.1. Management objectives

The Tsitsa Project vision is:

"To support sustainable livelihoods for local people through integrated landscape management that strives for resilient social-ecological systems and which fosters equity in access to ecosystem services."

As such the broad management objectives for the Tsitsa Project are:

- Minimise land degradation and erosion risk.
- Maintain and/or increase land productivity.
- Maximise forage production for livestock.
- Improve water quality (especially in summer) and quantity (especially in winter).
- Maintain or improve ecosystem services and ecological infrastructure.

2.2. Monitoring objectives

Monitoring is used to evaluate the current state of ecological infrastructure as well as the effects of management on the condition of ecological infrastructure. The following monitoring objectives have been preliminary chosen for the Tsitsa Project (Schlegel *et al.*, 2019):

- Compare baseline conditions of areas that are using different management approaches e.g. grazing and fire.
- Monitor how different management systems affect the condition of ecological infrastructure over time.
- Monitor changes in the landscape as a whole because of natural biophysical conditions (e.g. climate, pests, disasters etc.)

2.3. Indicators and measured variables

The Tsitsa Project Biophysical Monitoring Group's selection of the catchment indicators began with a review (Schlegel *et al.,* 2019) of existing monitoring plans and programs from around the world (e.g. Northern Colorado Plateau Inventory and Monitoring Network; Vital Signs Monitoring Plan; U.S National Park Service; Action Against Desertification; FAO United Nations etc.). This review provided a list of catchment biophysical indicators that are used in similar situations elsewhere. The review resulted in relevant indicators that could be summarized along the following themes (Figure 3):

- Climate (Rainfall);
- Land/Terrestrial systems: Terrestrial ecosystems, land cover and land use, which included indicators of changing land use/land cover, fire dynamics, and important ecosystems such as grasslands, forests, riparian vegetation and wetlands, as well as alien vegetation; and
- Water systems, which included indicators of hydrology, water quality and aquatic ecology.

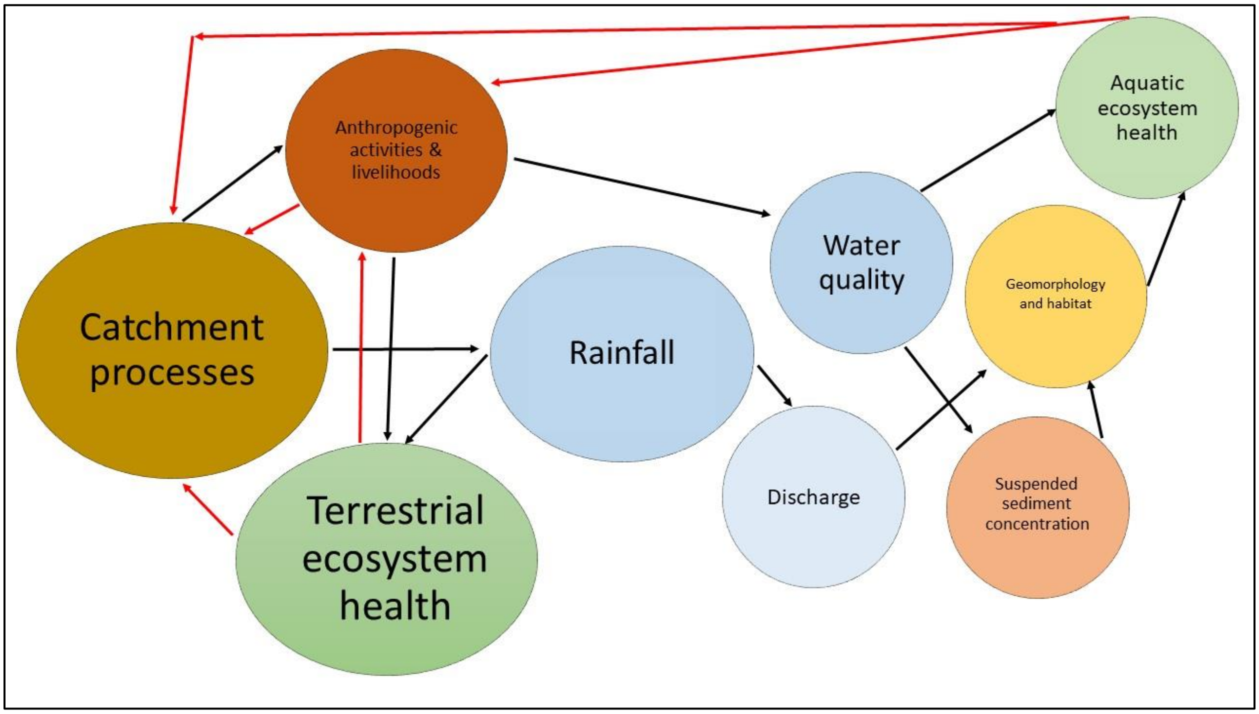


FIGURE 3: MONITORING FRAMEWORK SHOWING THE LINKS BETWEEN CATCHMENT PROCESSES

Table 1 shows indicators and measured variables under different domains and themes that have been adopted for the current biophysical monitoring in the Tsitsa Catchment.

Variables are measured at different time scales (Table 2). Monitoring of in-depth variables occur on a seasonal basis whereas catchment wide mapping of ecosystems occurs at longer time scales.

This is discussed in more detail in the full report by Schlegel *et al.* 2019.

TABLE 1: TABLE SHOWING INDICATORS AND MEASURED VARIABLES UNDER DIFFERENT DOMAINS AND THEMES

Theme	Domain	Indicators	Measured variables
Climate	Regional rainfall	Rainfall trend over time	Rainfall (mm)
Land	Geomorphology	Hillslope features and processes	Connectivity (m/ha) Erosion (m^3) Gully expansion (%)
	Terrestrial ecosystems	Fire dynamics	Fire frequency, location, intensity, extent, severity (% or ha)
		Grasslands	Condition, species composition, grazing value
		Forests	Extent (% or ha)
		Riparian zones	Extent, composition, condition (% or ha) VEGRAI assessment
		Wetlands	Size, type, location, condition, dominant species (% or ha)
		Alien vegetation	Extent, composition, density, age (% or ha)
Water	River ecosystems	Hydrology	Base flow monitoring ($m^3.s^{-1}$) Flood peaks ($m^3.s^{-1}$)
		Water quality	pH; Electrical conductivity; Temperature; Dissolved Oxygen; Nitrates; Phosphates; Turbidity; Clarity; Suspended Sediment Concentration (mg/l^{-1})
		Aquatic macroinvertebrates	SASSv5 assessment
		River channel characteristics	Classification of river channel

TABLE 2: BREAKDOWN OF MONITORING STRATEGY

	Rainfall	Terrestrial Ecosystems							River Ecosystems		
	Tip-bucket rain gauges	Hillslope features and processes	Fire Dynamics	Grassland condition	Forests	Riparian zones	Wetlands	Alien vegetation	Hydrology	Water Quality	Channel classification
Dry season monitoring			■							■	■
Wet season monitoring				■		■	■			■	
Continuous data collection	■								■	■	
≥ 5 Yearly mapping		■	■		■	■	■	■			■

3. BIOPHSYICAL MONITORING METHODS (HUCHZERMEYER *ET AL*., 2019A)

Huchzermeyer *et al.* (2019a) set out the methods for the biophysical monitoring done to date for the Tsitsa Project and includes details on monitoring sites and the methodology for data collection.

The current monitoring sites are indicated in (Figure 4) and coordinates are given in Table 3. The GIS shapefiles and Google Earth (.kml) layers can be made available on request.

Sites were adapted from previous studies (e.g. Huchzermeyer, 2017; Bannatyne, 2018; Nyamela, 2018) where the data already collected is invaluable for the biophysical monitoring. In addition new sites were chosen (veld monitoring and wetlands monitoring). Sites are discussed in more detail in the full report of Huchzermeyer *et al.,* 2019a).

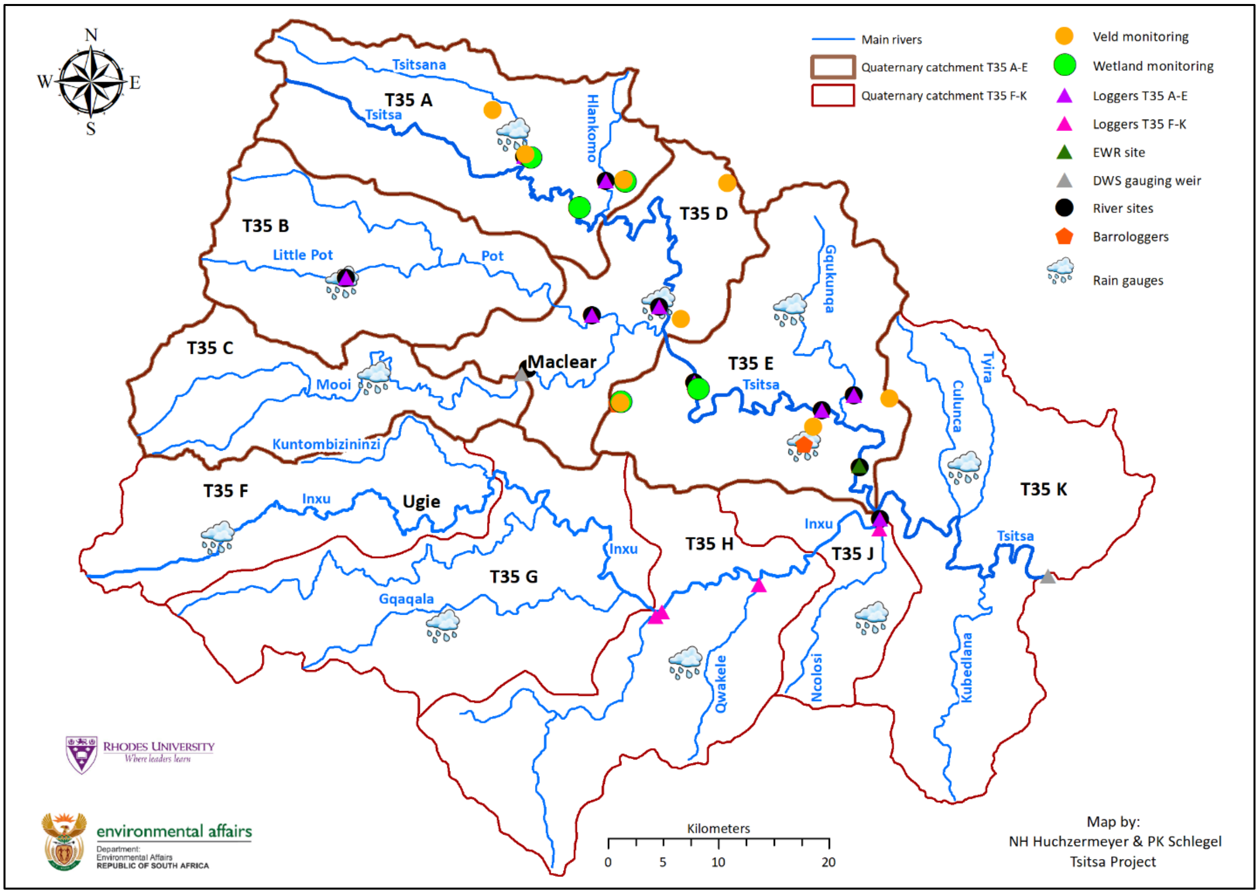


FIGURE 4: CURRENT MONITORING LOCATIONS IN THE TSITSA RIVER CATCHMENT.

TABLE 3: TABLES SHOWING SITE COORDINATES FOR BIOPHYSICAL MONITORING

	Raingauges	
Quaternary Catchment	**Site name**	**Coordinates**
T35 A	Tsitsana	30°52'35,637"S 28°20'49,83"E
T35 B	Woodcliffe	30°59'46,764"S 28°11'2,851"E
T35 C	Mooi/PG Bison	31°4'28,345"S 28°12'49,763"E
T35 D	Tsitsa Falls	30°52'35,637"S 28°20'49,83"E
T35 E	Sinxaku	31°7'49,957"S 28°37'14,8"E
T35 E	Gqunqunka	31°1'14,822"S 28°36'29,546"E
T35 F	Morvan	31°8'58,61"S 28°46'23,176"E
T35 G	Montgomery	31°8'58,61"S 28°46'23,176"E
T35 H	Mposa/Mphele	31°18'29,535"S 28°30'27,211"E
T35 J	Ntsiqo/Nosandise	31°16'21,1"S 28°41'4,781"E
T35 K	Tyirha/Nkosana	31°8'58,61"S 28°46'23,176"E

River Sites					
Quaternary Catchment		**Site name**	**Coordinates**	**Current biomonitoring site**	**Depth logger present**
Catchment T35 A-E	T35 A	Tsitsana (Ta)	30°53'39,079"S 28°21'27,655"E	Yes	Yes
	T35 A	Hlankomo (H)	30°54'53,554"S 28°26'5,285"E	Yes	Yes
	T35 B	Little Pot (LP)	30°59'33,426"S 28°11'16,404"E	Yes	Yes
	T35 C	Mooi Gauging Weir (T3H009)	31°4'17,951"S 28°21'12,944"E	No	Yes
	T35 D	Pot (P)	31°1'27,413"S 28°25'14,975"E	Yes	Yes
	T35 D	Mooi (M)	31°4'56,623"S 28°22'31,692"E	Yes	No
	T35 D	Tsitsa 4 (T4)	31°1'3,516"S 28°29'3,691"E	Yes	Yes
	T35 E	Tsitsa (T3)	31°4'46,461"S 28°31'3,371"E	Yes	Yes
	T35 E	Gqunqunka (G)	31°5'25,075"S 28°40'7,227"E	Yes	Yes
	T35 E	Tsitsa 2 (T2)	31°6'9,711"S 28°38'17,933"E	Yes	Yes
	T35 E	Tsitsa EWR (N3)	31°8'51,776"S 28°40'24,946"E	Yes	Yes

Catchment T35 F-K	T35 J	Inxu	31°11'28,447"S 28°41'35,739"E	Yes	Yes
	T35 J	T35 F-K_1	31°11'59,542"S 28°41'32,688"E	No	Yes
	T35 H	T35 F-K_2	31°14'40,635"S 28°34'40,968"E	No	Yes
	T35 H	T35 F-K_3	31°15'59,122"S 28°29'9,101"E	No	No
	T35 H	T35 F-K_4	31°16'12,964"S 28°28'46,475"E	No	Yes
	T35 K	Tsitsa Gauging Weir (TN2/T3H006)	31°14'17,033"S 28°51'7,962"E	No	Yes

Veld monitoring site		
Quaternary Catchment	**Site name**	**Coordinates**
T35 E	Veld 1	31°6'57,087"S 28°37'48,203"E
T35 E	Veld 2	31°5'35,652"S 28°42'8,88"E
T35 E	Veld 3	31°5'45,254"S 28°26'50,222"E
T35 A	Veld 4	30°51'23,031"S 28°19'39,928"E
T35 A	Veld 5	30°53'33,566"S 28°21'31,205"E
T35 A	Veld 6	30°54'49,959"S 28°27'4,896"E
T35 D	Veld 7	30°54'49,959"S 28°27'4,896"E
T35 D	Veld 8	30°54'49,959"S 28°27'4,896"E

Wetland monitoring site		
Quaternary Catchment	**Site name**	**Coordinates**
T35 E	Wetland 1	31°5'6,438"S 28°31'15,131"E
T35 E	Wetland 2	31°5'40,528"S 28°26'52,817"E
T35 A	Wetland 3	30°53'40,266"S 28°21'47,154"E
T35 A	Wetland 4	30°56'18,568"S 28°24'26,736"E
T35 A	Wetland 5	30°54'56,264"S 28°27'20,945"E
T35 D	Wetland 6	30°54'43,458"S 28°33'5,555"E
T35 B	Wetland 7	30°59'57,904"S 28°13'23,335"E

Barologgers		
Quaternary Catchment	**Site name**	**Coordinates**
T35 E	Green village	31°7'49,742"S 28°37'17,42"E
T35 D	Bob's Place	31°5'47,628"S 28°26'38,861"E

4. BIOPHYSICAL MONITORING: REPORT 1 OF THE UPPER TSITSA RIVER CATCHMENT (HUCHZERMEYER *ET AL.*, (2019B)

This report focused on the main results for the Biophysical Monitoring done to date (2019) for the Tsitsa Project and includes details on monitoring sites, the condition of each site and relevant data and observations.

The current monitoring accesses rainfall, water quality and quantity, river, wetland and veld condition in Catchment T35 A-E. Figure 6 summarises the current condition of the Tsitsa Catchment as per the results of the biophysical monitoring up until April 2019. A summary of the key findings from Huchzermeyer *et al.,* 2019b is reported below.

4.1. Rainfall

A total of 11 self-logging tipping rain gauges are currently managed by the biophysical monitoring team. The location, magnitude, duration and extent of rainfall plays an important role in the effects of different catchment processes. The rainfall data presented in this report can be used to help aid the interpretation of catchment processes and can be linked to spikes in hydrology, increased sediment yields etc. Annual rainfall in the catchment has increased from 2015 with a general trend showing higher average rainfall at higher altitudes particularly closer to the Drakensberg escarpment (Figure 5). Rainfall at monitoring sites higher up in the catchment receive annual rainfall of greater than 700 mm/year (T35 A, B, C, F). Sites in the lower and middle catchment receive rainfall between 500-600 mm/year (T35 D, E, G, H, J, K). The highest intensity rainfall events are found in the North-western part of the catchment. Maximum 5 minute rainfall events at Catchment T35 A, B & D exceeded 13 mm/5 minutes (156 mm/hour). Catchment C, E & G exceeded 10 mm/5 minutes (120 mm/hour) and Catchment F, H, J & K exceeded 6 mm/5 minutes (72 mm/hour).

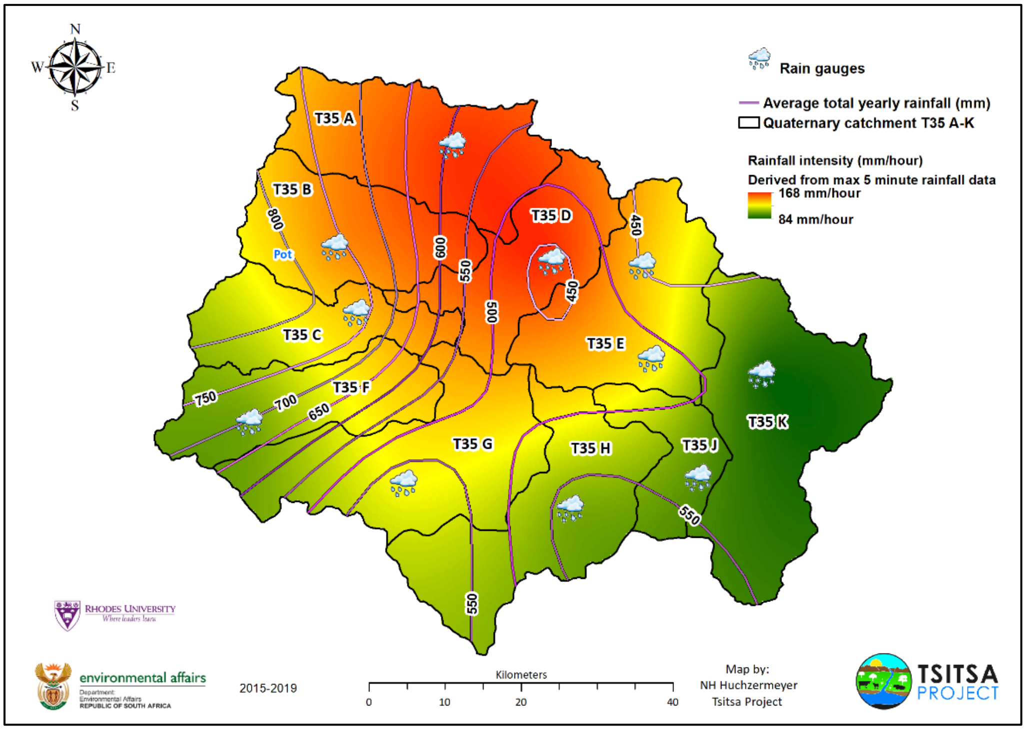


FIGURE 5: RAINFALL TRENDS IN THE GREATER TSITSA CATCHMENT (2015-2019)

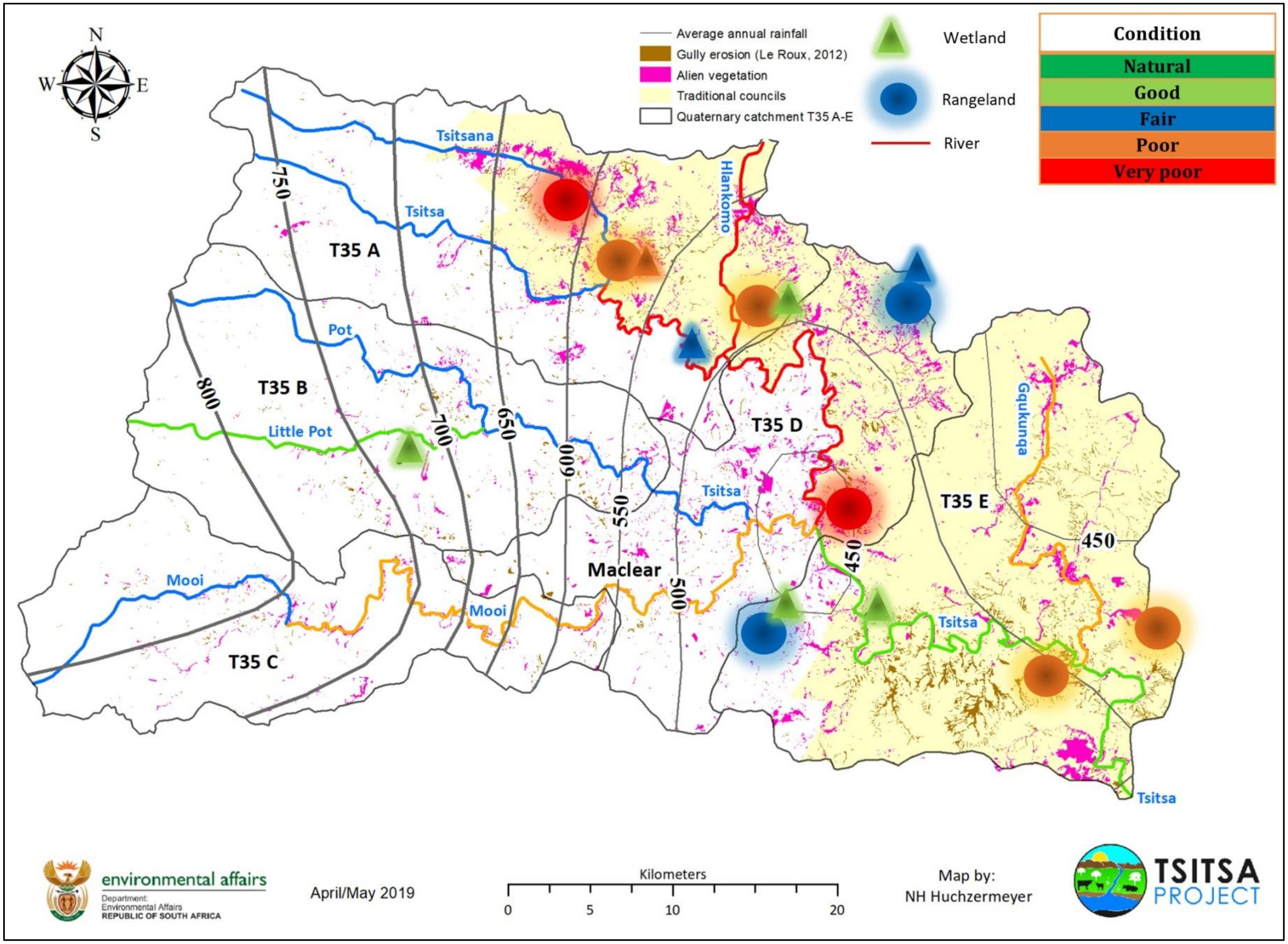


Figure 6: Condition of the Tsitsa Catchment following field surveys in April 2019

4.2. Hydrology and River Monitoring

The health of rivers are an important indicator of the catchment processes occurring in the catchment in which the river is situated. There are currently 11 river monitoring sites at which a combination of hydrology, water quality and geomorphic (habitat) condition are being monitored. Discharge and flow velocities play an important role in sediment mobility and the stability of beds. All the sites show similar trends in discharge fluctuations with total discharge increasing further down the catchment. Months with little or no rainfall generally have low discharge values. Discharge peaked during summer months due to heavy rains in the catchment. Local rainfall events can increase the discharge significantly, particularly at the start of the rainy seasons. Snowmelts (e.g. August 2016) can also cause spikes in discharge during the winter months. Peak discharges at the start of the monitoring period (2016) were well below average but have been rising with increased rainfall in the catchment in subsequent summer months. The peak discharge in 2019 exceeded the 10 year flood indicating very high discharges for the season.

Monitoring water quality variables gives an indication of the health of aquatic habitats. Five variables were identified for a short-term habitat assessment, namely dissolved nitrogen and phosphate concentrations, pH, electrical conductivity (EC), dissolved oxygen (DO) content and water temperature.

Overall the water quality indicated a balanced system with the exception of increased phosphate levels and turbidity and the reduction in clarity due to high suspended sediment concentrations in flood waters. Phosphate levels for April 2019 ranged from 0 - 0.6 across all the sites. The highest levels were measured during a flooding event and levels of phosphate dropped with the reseeding flood. Concentrations of phosphates need to be considerably higher than those found in the rivers to have a significant impact on biotic health (Dallas & Day, 2004). The health effects of drinking water with phosphates are not well documented. Natural levels of nitrates are generally <1mg/l. Concentrations of >10 mg/l are seen as detrimental to aquatic life and human consumption. Most of the sites exhibit Nitrate levels of <1 mg/l in April 2019 with the exception of Site T2 on the Tsitsa River which was 1.6 mg/l. This is not seen as being detrimental to the health of the river at the site. DO levels ranged between 98 -114%. None of the DO concentrations fell below 50%, which is defined as sub-lethal to aquatic organisms (DWAF, 1996). Therefore, concentrations of DO were not expected to have any significant impacts on biotic health in the rivers. A well buffered South African river will be expected to have a pH ranging between 6 and 8, but fluctuations occur due to a changes in temperature, photosynthetic activity or biotic respiration and decomposition of organic matter (DWAF, 1996; Dallas & Day, 2004). Measured pH at most of the sites in April 2019 ranged from 7.3 - 8.0. Site T4 on the Tsitsa River exhibited a higher pH value of 9.6. According to Dallas & Day (2004) very little information is available on the tolerance of aquatic organisms to increased conductivity. The rate of change rather than the absolute change is important in assessing the effects on organisms. EC ranged from 20-60 µS/cm for April 2019. Turbidity increased and clarity decreased progressively with higher discharges and further down the river system. This can be linked to an increase in erosion and transport soil and sediment. Increased suspended sediment (greater turbidity and reduced clarity) has a significant effect on water and habitat quality particularly during the summer months. This is possibly the largest water quality issue for local livelihoods as the river water cannot be used for household purposes during a large part of the summer months.

Macroinvertebrates provide barometers of river health as they are the first to register ill effects of negative impacts on a river system. River health, in terms of water quality, can be rapidly assessed by looking at the taxa richness of macroinvertebrate species sensitive to water quality (Dickens & Graham, 2002). A score derived using the South African Scoring System Version 5 (SASSv5) (Dickens & Graham, 2002), a widely used technique in South African Rivers, was calculated for each site as a time integrated assessment of water quality. This gave a measure of river health at the site scale. The average score per taxa (ASPT) is the total sensitivity score for all the families found, divided by the number of families found.

The SASSv5 scores are reported for each monitoring sites for April/May 2019 and give an indication of the ecological condition of the river at the monitoring site and the river upstream of the site. The ASPT score for April/May 2019 ranged from 4.9 - 7.5 across all the monitoring sites indicating ecological conditions ranging from very poor to good (Figure 6). A reduction in the ASPT scores and ecological conditions at each site can be attributed to the lack of habitat (mostly due to the embeddedness of coarse substrates) at these sites (due to erosional catchment processes and bed gradient) and high flows with turbid waters experienced during the monitoring survey. Site T4 on the Tsitsa River (ASPT score: 4.9) and Hlankomo River (ASPT score: 5) exhibited a very poor ecological condition. The Gqukunqa River (ASPT score: 5.8), Inxu River and the Mooi River (ASPT score: 6) exhibit a poor ecological condition. The Tsitsana River and Pot River (ASPT score: 6.7) exhibit a fair ecological condition. The Little Pot River (ASPT score: 7.1), the Tsitsa River at lower sites T3 and NH3 (ASPT score: 7.2) and the Tsitsa River at Site T2 (ASPT score: 7.5) exhibit a good ecological condition. Figure 6 shows the location of river monitoring sites and their condition in the context of Catchment T35 A-E.

A review of the common macroinvertebrate families of the upper Tsitsa River Catchment and their associated habitats with an emphasis on fine sediment accumulation can be found in the report. The following trends were observed and documented in the Tsitsa River. Shallow pool areas and areas of reduced flow are highly embedded with high concentrations of sediment drape and commonly not suitable for many families of macroinvertebrates that prefer some sort of coarse substrate or aquatic vegetation to cling onto. In areas where flow velocity was sufficient to wash away fines (eg. cobble riffles), macroinvertebrate abundance and diversity increased and the river maintained a more natural condition. Macroinvertebrates seek refuge in aquatic and marginal vegetation during highly turbid flows. Presence of vegetation in sites containing fine sediment deposits increased the macroinvertebrate diversity. Lack of vegetation, low flows and depths and high concentrations of fine sediment with a low substrate diversity decreased macorinvertebrate diversity. In rocky habitats in the Tsitsa River, the presence of diverse macroinvertebrate families was found to be mainly affected by substrate diversity. The more diverse the substrate the more habitats are available for colonisation by macroinvertebrate families. However, excessive deposition of fine sediment on the bed of the river decreased the substrate diversity and available habitats, in turn reducing the number of macroinvertebrate families present that were sensitive to sediment drape and in some cases increasing the number of less sensitive families. In habitats dominated by fines macroinvertebrate families that were less sensitive to fine sediment drape become more abundant. In patches where fine sediment accumulation was excessive, such as on thick silt deposits, macroinvertebrate abundance was observed to decrease. Excessive sedimentation in a river system has a direct impact on various aquatic trophic levels. Macroinvertebrates that naturally occur in rocky habitats decreased in abundance with an increase in fine sediment accumulation, due to a reduction of habitats through the filling of interstitial spaces and rocky substrates becoming draped by fine sediment. Macroinvertebrates that naturally occur in sandy habitats and crawl along substrate or are air breathers, diving in the water column or thriving on the surface of the water, are less affected and are possibly benefited by an increase in fine sediment accumulation.

4.3. Terrestrial Biophysical Monitoring

Land cover/use, landscape connectivity and ecosystems have been mapped using a combination of medium-resolution satellite imagery, higher-resolution aerial imagery and field verification (Huchzermeyer *et al*., 2018a; Huchzermeyer, *et al*., 2018b & Schlegel *et al*., 2018). A base-line map, classifying land cover at a catchment-scale, of the catchment was generated. Mapping of these ecosystem components will be mapped on a ≥ 5 yearly interval. These datasets are used by catchment managers for integrated planning and prioritisation.

Landscape connectivity over the past 100 years has been enhanced by the formation of gullies, livestock tracks and roads (Van der Waal & Rowntree, 2017). The downslope and across slope connectivity is monitored by mapping connectivity features such as gullies, livestock paths, and roads and calculating a percentage increase or decrease in connectivity. Cross-slope or horizontal drainage features such as roads, jeep tracks and livestock tracks drain, concentrate and route overland flow directly into drainage networks, preventing water infiltration and sediment storage. Livestock tracks were by far the most dense and extensive, whereas main roads were high in urban centres, but limited in spatial extent. Down-slope connecters, such as gullies are not as widespread throughout the catchment, but are very effective at draining areas that can store sediment (low angled slopes) and routing sediment to the larger channels. Increases in hydrological and sediment connectivity were largest around villages on communal land.

Snyman (2019) is using Landsat imagery to extract burn scars in Catchment T35 A-E. A time-series analysis is being used to calculate fire frequency and MODIS/VIIRS point data is used to monitor the timing and intensity of fires. This data can then be used to help interpret catchment processes and aid management interventions. Preliminary findings show that:

- there is a decrease in the area of fire scars over the past 30 years,
- fire scars are larger in the upper catchment and smaller in the middle and lower catchment, especially in the traditional council areas,
- fire frequency is highest in the upper catchment,
- fire intensity is highest in the upper catchment.

Veld Condition Assessment:

The Tsitsa river catchment vegetation is dominated by grassland (Mucina & Rutherford, 2006). Grasslands are an important resource for the people living within the catchment. However, grasslands in the Tsitsa Catchment are characterised by many symptoms of veld degradation with the most prominent being large-scale and severe erosion and the encroachment of alien vegetation.

One of the driving forces behind this degradation is the lack of grazing and fire management systems. To assess the current veld condition, veld monitoring sites were chosen that represent different land-use areas, geology, elevations and vegetation types. Phase 1 of the veld condition assessment is focused in the traditional council areas. A total of 8 sites were chosen for monitoring. This report unpacks the veld condition for each site and includes dominant grass species, biomass, veld condition and grazing capacity. Sites classified as having a very poor veld condition (Site 4 & 8) occur on abandoned cultivated lands were the soil structure has been previously disturbed and not given enough time to recover. These sites are heavily utilized and have low biomass values (> 960 $kg.ha^{-1}$) and only poor grazing grass species are present with large areas of bare ground. These sites are also located on the mudstones of the Elliot and Molteno geological formation. These mudstones are highly erodible particularly when the vegetation cover is inhibited.

Sites classified as having a poor veld condition (Site 1, 2, 5 & 6) are heavily grazed with biomass ranging from 1 000-2 000 $kg.ha^{-1}$. Higher biomass values are present because the sites are located in lower gradient areas where water accumulates stimulating plant growth (e.g. close to wetlands, on alluvial deposits next to rivers or mid-slopes). There is less bare ground visible than in the sites classified as having a very poor veld condition.

Two sites were classified as having a moderate veld condition (Site 3 & 7). Site 3 is located in a managed grazing camp on a private farm and exhibits grasses that provide good grazing despite lower levels of grass biomass than other sites (1 592 $kg.ha^{-1}$). Site 5 is located on a valley bottom close to a wetland and exhibits the highest biomass of all the sites (2 667 kg.ha^{-1}). Both sites exhibit good grass cover with minimal bare ground and occur at altitudes of greater than 1 350 meters above sea level.

Biomass readings of 4 000 kg.ha^{-1} or more exhibit high biomass and only then would they benefit from a prescribed burning. Many of the sites are nowhere near this goal for biomass requiring up to 4.5 times the amount of biomass before pre-scribed burning should be considered. Overgrazing is commonly not a function of intensity but rather a function of frequency. Because the catchment is dominated by mudstones that are highly erodible it is important to maintain healthy vegetation cover throughout the catchment. All the sites would benefit by prolonged rest periods to allow for the stabilization of grass and other important plant population through re-growth and full seed production.

Wetland Monitoring:

Over 2 800 wetlands were identified covering a total area of over 7 600 ha, ranging from larger valley bottom wetlands to smaller hillslope seep wetlands (Schlegel *et al.,* 2018). A range of wetlands (7 sites) was chosen to investigate their current condition, species composition and look at their effectiveness as sediment buffers in the landscape at a course scale. Most of the investigated wetlands were found to be in a good to fair condition and are acting as important sediment sinks in the landscapes. The biggest risks to the wetlands are alien vegetation, erosion at the toe of the wetlands and potential incision of drainage lines that will reduce the buffering function of the wetland floodplain and enter the main river channels directly.

4.4. Forests (Huchzermeyer *et al.,* 2018a)

Indigenous vegetation (both forests and other smaller woody species) are important **biodiversity hot spots** that also provide a variety of building materials and are important for cultural (fighting sticks and bark for medicine) and spiritual values (Geldenhuys *et al.,* 2016; Ngwenya, 2016). There are a total of 4 243 patches in Catchment T35 A-E dominated by indigenous plants, with a total area of 3 985 ha (this excludes patches of vegetation that have indigenous plants but are dominated by alien vegetation). Of this 466 (1 575 ha) were identified as Indigenous Forest patches and 3 777 (2 410 ha) patches were identified as other indigenous vegetation (small trees, shrubs and bushes). The indigenous forests occur in fire shadow areas of ravines and steep south facing slopes that are commonly protected by cliffs. Assessments of forests pointed to a healthy population structure, but fire and alien pressures do threaten the outer limits of the forests (Geldenhuys *et al.* 2016). Restoration and management are needed to improve the quality and sustainability of indigenous forests and to reduce alien vegetation spread into natural forests.

4.5. Alien Vegetation (Huchzermeyer *et al.,* 2018a; Huchzermeyer *et al.,* 2019c)

Alien plant species are those species that are considered non-indigenous to an ecosystem. South Africa has a long history of problems with Invasive Alien Plants (IAPs) and corresponding research and management of biological invasions.

A total of 37 dominant alien woody species were identified in Catchment T35 A-E of which 7 species (silver wattle, black wattle, green wattle, poplar, eucalyptus, pine and Mauritius thorn) are invading hillslopes, riparian zones and indigenous vegetation on a large scale. Approximately 51% of the area covered by alien woody vegetation occurs on hillslopes, 43% in the riparian zones and the remaining 6% are spreading from drainage lines, plantations, gardens and woodlots. 56% of the alien vegetation category was verified in the field. From the alien vegetation category verified in the field only 3% was noted to be actively used and harvested to such an extent that it was no longer spreading. This is particularly evident within close walking distance of villages.

The main alien species in Catchment T35 A-E can be detailed as follows:

- **Silver wattle:** A total of 6 955 patches (uncondensed area of 5 502 ha). Of those 3 671 (3 326 ha) of the patches consist of 50 percent and above Silver wattle.
- **Black wattle:** A total of 280 patches (uncondensed area of 262 ha). Of those, 246 (239 ha) of the patches consist of 50 percent and above Black wattle.
- **Green wattle:** A total of 441 patches (uncondensed area of 222 ha). Of those, 243 (97 ha) of the patches consist of 50 percent and above Green wattle.
- **Black and Green wattle co-existing:** A total of 6 675 patches (uncondensed area of 5 398 ha).
- **Mauritius thorn:** A total of 60 patches (uncondensed area of 3.8 ha). However, there might be a higher abundance as they are difficult to identify off aerial photographs and commonly occur in drainage lines and gullies where remote sensing techniques are limited.
- **Eucalyptus species:** A total of 1 028 patches (uncondensed area of 1 293 ha) occur outside of the plantation areas. Of those, 331 (343 ha) of the patches consist of 50 percent and above Eucalyptus species.
- **Pine species:** There are a total of 228 patches (uncondensed area of 137 ha) occur outside of the plantation areas. Of those, 39 (21 ha) of the patches consist of 50 percent and above Pine species.
- **Poplar species:** A total of 917 patches (uncondensed area of 1 099 ha). Of those 190 (160 ha) of the patches consist of 50 percent and above of Poplar species.

4.6. Data management

The Tsitsa Project Biophysical Monitoring Group is a steward of the data that is a product from our inventory and monitoring work in the Tsitsa River Catchment. While this information is useful and crucial today, it will become even more valuable in the years and decades to come. From planning, to field work, and through to analysis, priorities are placed on:

- Data Accuracy.

  The quality of the biophysical data we collect is paramount. Analyses to detect trends or patterns require data with minimal error and bias.
- Data Security.

  Data is protected against loss.
- Data Longevity.

  Data sets need to be cared for. Processing documentation will accompany all data sets.
- Data Accessibility.

  Data will be made available in a variety of formats to any interested and affected stakeholders through the TP knowledge hub.
- Student data collection warrants an embargo period in which a full dataset cannot be shared until the student has published and released their data.

5. INDICATOR PROTOCOLS FOR THE TSITSA PROJECT

Indicator protocols for 6 biophysical indicators that were identified as essential for the Tsitsa Project were identified by the biophysical monitoring group and PMERL group. These protocols are presented in a standardized summarized format (with help from the PMERL group) which includes the type of indicator, why, what, where & how it is measured. These are presented in this chapter together with some key outcomes from the first monitoring report (Huchzermeyer *et al*. 2019b).

5.1. River health

Tsitsa Project Indicator Reference Sheet
Name of Result Measured (impact, outcome, output, process): Outcome
Name of Indicator: River health
DESCRIPTION
Precise Definition(s): River health in terms of water quality at the site scale, as indicated by the taxon richness of aquatic macroinvertebrate species sensitive to water quality (Dickens & Graham, 2002).
Type of indicator: Quantitative (composite score)
Unit of Measure: A score derived using the South African Scoring System (SASS) version 5
Integration with other indicators: The suspended sediment indicator data can be used to aid interpretation of the SASS data. The SASS data are also supplemented with water quality data from each river monitoring site (dissolved nitrogen and phosphate concentrations, electrical conductivity, pH, dissolved oxygen, water temperature and turbidity). Fluvial geo-habitats are also recorded. Details in: Huchzermeyer, N., Schlegel, P. & vd Waal, B. (2019). *Biophysical Monitoring Methods in the Upper Tsitsa River Catchment (T35 A-E)*. Tsitsa Project Report, June 2019. Rhodes University/DEFF.
Disaggregated by: Site
Rationale or Justification for indicator: The health of rivers is an important indicator of catchment processes. River health, in terms of water quality, can be rapidly assessed by looking at the taxon richness of macroinvertebrate species sensitive to water quality (Dickens & Graham, 2002). This is a widely used technique in South African rivers. A comparison of trends over time and under different flow conditions can indicate improvement or degradation of the aquatic ecosystem.
PLAN FOR DATA COLLECTION
Data Source: Field sampling of macroinvertebrates
Method of data collection: SASS v5 is carried out at each river monitoring site to obtain a rapid assessment of water quality, using the standard recording template (see Huchzermeyer et al., 2019). This gives a measure of river health at the site scale. A specified net with fine mesh is held downstream of the sample point to catch macroinvertebrates dislodged from the substrate or marginal vegetation. Fine sediments are sieved through the net and visual observations of substrate and vegetation conducted to record further habitat niches. The macroinvertebrates are then placed in a tray and identified. The average score per taxon (ASPT) is the total sensitivity score for all the classes/families found, divided by the number of classes/families found. Changes in habitat result in changes in the types of organisms and give a clear indication of the current condition of a river channel. SASS scores may be used to place a site into one of five ecological categories (A—natural, B—good, C—fair, D—poor

and E—very poor). The SASS scores are reported for each monitoring site and give an indication of the ecological condition of the river at the monitoring site and upstream of the site.

Mini-SASS, a simplified version of the full SASS, will be carried out periodically (roughly 5 times per year) by school groups in the area, to supplement the above data but also as a participatory educational experience.

Reporting Frequency: Annually

Individual(s) responsible: Biophysical Monitoring Group (Nicholaus Huchzermeyer)

Location: River monitoring sites (see details in Huchzermeyer, N., Schlegel, P. & vd Waal, B. (2019). *Biophysical Monitoring Methods in the Upper Tsitsa River Catchment (T35 A-E)*. Tsitsa Project Report, June 2019. Rhodes University/DEFF).

DATA QUALITY ISSUES

Known Data Limitations: Aquatic invertebrates respond relatively rapidly to changes in water quality or habitat conditions. Scores therefore reflect conditions in the river over a period of less than a week prior to the sampling, which may or may not reflect the "usual" conditions. Supplementary data on flow and water quality can be used to interpret the SASS scores.

Habitat quantity, quality and diversity must be taken into consideration when interpreting the SASS scores (Graham et al., 2004). Habitat diversity can be linked to the diversity of biota present. This will be evident when looking at the SASS score. The ASPT score is less affected by the biota present at each site because the biota may have representative sensitivities to the water quality present at the site. The SASS score may be high due to many taxa being present because of a diversity of habitats. But if these taxa all have low sensitivity scores then the ASPT score will be lower, or if the taxa exhibit high sensitivity scores the ASPT will he higher. Therefore, the ASPT is the more reliable measure of good quality rivers (Graham et al., 2004). The ASPT score should be interpreted with caution when the SASS score is very low (Dallas, 2007).

Dates of Previous Data Quality Assessments, methods and name of reviewer:

Dates of Future Data Quality Assessments *(optional)*:

BASELINE

Baseline timeframe (optional): Values from April 2019 are reported in Huchzermeyer, N., Schlegel, P. & vd Waal, B. (2019). Biophysical Monitoring Report 1 of the Upper Tsitsa River Catchment (T35 A-E). Tsitsa Project Report, August 2019. Rhodes University/DEFF.

Within the range of parameters monitored in April 2019, water quality did not alter the types of macroinvertebrates that would naturally occur in the river. This corresponds to the findings of Madikizela & Day (2003) in the Mzimvubu River and its tributaries including the Tsitsa River, and Huchzermeyer (2017) on the Tsitsa River. Madikizela & Day (2003) established that macroinvertebrate families in the Mzimvubu River and its tributaries were not found in abundance but species sensitive to poor water quality were present. Huchzermeyer (2017) monitored the Tsitsa River from 2015–2016, a period characterised by a combination of low discharges (causing an increase in bed sediment storage) and lack of water quality influences, to determine the effect of fine sediment accumulation on macroinvertebrates. A review of the common macroinvertebrate families of the upper Tsitsa River Catchment and their associated habitats with an emphasis on fine sediment accumulation is given in Appendix 6 of Huchzermeyer, N., Schlegel, P. & vd Waal, B. (2019). Biophysical Monitoring Report 1 of the Upper Tsitsa River Catchment (T35 A-E). Tsitsa Project Report, August 2019. Rhodes University/DEFF.

SASS data are also available from previous work at site NH3/EWR, which has been used as a site for determining environmental flows for the Mzimvubu Catchment Partnership Programme as well as by Huchzermeyer (2017).

CHANGES TO INDICATOR
Changes to indicator:
Other Notes *(optional)*:
THIS SHEET LAST UPDATED ON: 13 January 2020

Initial results

Table 4 lists the SASSv5 data for April/May 2019. The SASSv5 scores are reported for each monitoring site and give an indication of the ecological condition of the river at the monitoring site and the river upstream of the site (see Figure 6). The sites are reported on from the top of the catchment moving downwards.

The SASSv5 survey on the Tsitsana River was undertaken under moderately high flow conditions following a flood event. The Tsitsana River had a SASS score of 107 which shows moderate habitat diversity. The dominant habitat present at the site during the monitoring survey included marginal vegetation, stones and sand. The ASPT score was 6.7 implying that the site is moderately modified. 16 taxa were found with a moderate average abundance. The **Tsitsana River** is classified as being in a **Fair ecological condition**.

The SASSv5 survey on the Hlankomo River was undertaken under moderately high flow conditions following a flood event. The water was noted to be very milky. The Hlankomo River had a SASS score of 95. This points toward a low habitat diversity present at the site. The dominant habitat present during the monitoring survey included bedrock, stones, marginal vegetation and sand. The ASPT was 5 implying a seriously modified river. 18 taxa were found with a low average abundance. The **Hlankomo River** is classified as being in a **Very Poor ecological condition**.

The SASSv5 survey on the Little Pot River was undertaken under moderate flow conditions following a flood event. The water was clear. The Little Pot River had a SASS score of 192 implying very high habitat diversity. All biotopes, except aquatic vegetation, were found at the site. The ASPT was 7.1 implying a largely natural river. 27 taxa were found with a moderate average abundance. The **Little Pot River** is classified as being in a **Good ecological condition**.

The SASSv5 survey on the Pot River was undertaken under high flow conditions during a receding flood. The Pot River had a SASS score of 160 implying a high habitat diversity. All biotopes with the exception of aquatic vegetation were sampled. The ASPT was 6.7 implying a moderately modified system. 24 taxa were found with low average abundance. The **Pot River** is classified as being in a **Fair ecological condition.**

The SASSv5 survey on the Mooi River was undertaken under moderately high flow conditions following a flood event. The Mooi River had a SASS score of 137 implying high habitat diversity. All biotopes with the exception of aquatic vegetation were sampled. The ASPT was 6 implying a largely modified system. A total of 22 taxa were found with moderate average abundance. The **Mooi River** is classified as being in a **Poor ecological condition.**

The SASSv5 survey on the Tsitsa River at site T4 was undertaken under high flow conditions during a receding flood. The water was turbid. The Tsitsa River had a SASS score of 64 implying very low habitat diversity. The dominant habitats present at the time of surveying were marginal vegetation, bedrock, gravel, sand and mud. The ASPT was 4.9 implying a seriously modified system. A total of 13 taxa were found with moderate average abundance. The **Tsitsa River at site T4** is classified as being in a **Very Poor ecological condition.**

The SASSv5 survey on the Tsitsa River at site T3 was undertaken under very high flow conditions during a flood. Water was turbid. The Tsitsa River had a SASS score of 144 implying a high habitat diversity.

The dominant vegetation habitats sampled included marginal vegetation, gravel, sand and mud. The channel was too deep to sample stones and bedrock. This may result in a reduced ASPT score. The ASPT was 7.2 implying a largely natural system with few modifications. A total of 19 taxa were found with a low average abundance. The **Tsitsa River at site T3** is classified as being in a **Good ecological condition.** The change in ecological condition between site T4 which is upstream of site T3 could be explained by the location of each site. Site T3 is situated at the bottom of a gorge with fast flowing water. This could result in less imbrication of substrate allowing for more habitat diversity for taxa.

The SASSv5 survey on the Tsitsa River at site T2 was undertaken under very high flow conditions during a flood. Water was very turbid. The Tsitsa River had a SASS score of 60 implying very low habitat diversity. The dominant vegetation habitats sampled were limited to marginal vegetation, sand, mud and gravel. The channel was too deep to access any other biotopes. The ASPT was 7.5 implying a largely natural system with few modifications. A total of only 8 taxa were found with a low average abundance. This is likely due to the flooding and lack of access to the full biotopes present at the site. The **Tsitsa River at site T2** is classified as being in a **Good ecological condition.**

The SASSv5 survey on the Tsitsa River at site NH3/EWR was undertaken under very high flow conditions during a flood. Water was very turbid. The Tsitsa River had a SASS score of 65 implying very low habitat diversity. The dominant vegetation habitats sampled were limited to marginal vegetation, sand and mud. The channel was too deep to access any other biotopes. The ASPT was 7.2 implying a largely natural system with few modifications. A total of only 9 taxa were found with a low average abundance. This is likely due to the flooding and lack of access to the full biotopes present at the site. The **Tsitsa River at site NH3/EWR** is classified as being in a **Good ecological condition.**

The SASSv5 survey on the Gqukunqa River was undertaken under high flow conditions during a flood. The water was turbid. The Gqukunqa River had a SASS score of 52 implying very low habitat diversity. All the biotopes with the exception of aquatic vegetation and bedrock were samples. The ASPT was 5.8 implying a largely modified system. A total of only 9 taxa were found with a low average abundance. The **Gqukunqa River** is classified as being in a **Poor ecological condition.**

The SASSv5 survey on the Inxu River was undertaken under high flow conditions during a flood. The water was turbid. The Inxu River had a SASS score of 42 implying very low habitat diversity. The Inxu River has very little habitat present and the only biotopes present are marginal vegetation, sand, mud and fine gravel. The ASPT was 6 implying a largely modified system. A total of only 7 taxa were found with a low average abundance. The **Inxu River** is classified as being in a **Poor ecological condition.**

Within the range of parameters monitored in April 2019, water quality could be discounted for having any noticeable effects in altering the types of macroinvertebrates that would naturally occur in the river. This corresponds to the findings of Madikizela & Day (2003) in the Mzimvubu River and its tributaries including the Tsitsa River and Huchzermeyer (2017) on the Tsitsa River. Madikizela & Day (2003) established that macroinvertebrate families in the Mzimvubu River and its tributaries were not found in abundance however, species sensitive to poor water quality were present. Madikizela & Dye (2003) identified that the secondary effects of sedimentation and reduction in habitat played an important role in the ecological health of a river and might cause a reduction in the abundance of certain macroinvertebrate families. Huchzermeyer (2017) monitored the Tsitsa River over a time (2015-2016) characterised by a combination of low discharges causing an increase in bed sediment storage and the lack of influence from water quality variables on macroinvertebrate community structure. This made conditions ideal for researching the effect that bed sediment was having on macroinvertebrates. A review of the common macroinvertebrate families of the upper Tsitsa River Catchment and their associated habitats with an emphasis on fine sediment accumulation can be found in Huchzermeyer *et al.,* (2019b).

TABLE 4: SASSv5 DATA FOR APRIL/MAY 2019

	Tsitsana	Hlankomo	Little Pot	Pot	Mooi	T4/Falls	T3/Gorge	T2/Bridge	NH3/EWR	Gqukunqa	Inxu
SASS score	107	95	192	160	131	64	137	60	65	52	42
No. of taxa	16	18	27	24	22	13	19	8	9	9	7
ASPT	6.7	5	7.1	6.7	6	4.9	7.2	7.5	7.2	5.8	6
Average dominant estimated abundance per taxon (A:1-10 low; B:10-100 moderate; C:100-1000 high; D:>1000 very high)	B	A	B	A	B	B	A	A	A	A	A
Ecological condition	Fair	Very Poor	Good	Fair	Poor	Very Poor	Good	Good	Good	Poor	Poor

5.2. Baseflow monitoring

Tsitsa Project Indicator Reference Sheet
Name of Result Measured (impact, outcome, output, process): Impact
Name of Indicator: Dry season baseflow
DESCRIPTION
Precise Definition(s): Minimum monthly discharge for the year
Type of indicator: Quantitative
Unit of Measure: Cubic metres per second (cumecs)
Integration with other indicators: Dry season baseflow is linked to indicators of catchment condition such as ground cover, wetland health and sediment retention (see Rationale). It reflects the integrated impact of several catchment processes. Water quality, river health (SASS) and the geomorphic condition of the channel are recorded at the same river monitoring sites. Discharge is recorded throughout the year, so data on high flows are also available. Rainfall is also monitored within each sub-catchment.
Disaggregated by: Sub-catchment (Each monitoring point represents its upstream catchment)
Rationale or Justification for indicator: Baseflow is the component of river flow maintained by groundwater and/or shallow subsurface storage. Through most of the dry season, river flow (discharge) is composed entirely of baseflow. During the wet season, discharge is made up of baseflow and quickflow. The latter represents the direct catchment response to rainfall or snowmelt events. Baseflow is particularly important in regions with long dry seasons, such as the Tsitsa catchment. Maintenance of baseflows during the dry season implies a healthy catchment (sufficient ground water recharge, vegetation cover, functional wetlands, enabling the catchment to act as a “sponge” and discharge water into the rivers gradually over time). Long-term changes in baseflow can indicate a decline in the ability of the catchment to provide this important ecosystem service or excessive abstraction of surface and ground water. Baseflow is thus a key consideration in integrated water resources management (IWRM). Maintenance of baseflows is important for sustaining aquatic ecosystems and also for sustainable access to water by local people as an alternative water source (when rain tanks, boreholes and springs fail). It underpins the United Nations Sustainable Development Goal (SDG) 6, to “ensure availability and sustainable management of water and sanitation for all”.
PLAN FOR DATA COLLECTION
Data Source: DWS gauging stations plus network of flow loggers (Solinst level loggers) installed under the Tsitsa Project.
Method of data collection: Data from the flow loggers is downloaded once a year. The “raw” data is a time series of variations in depth (water pressure above the logger) and temperature, measured at 20 minute intervals. These data are converted into a suitable format and corrected for atmospheric pressure fluctuations using data from 2 Solinst Baraloggers installed in the catchment. Discharge is calculated from the measured water levels using rating curves (discharge vs water level) developed for each site. Data from the DWS gauging stations (monthly, daily or 6 min continuous data) is obtained from DWS. Further details in: Huchzermeyer, N., Schlegel, P. & vd Waal, B. (2019). *Biophysical Monitoring Methods in the Upper Tsitsa River Catchment (T35 A-E)*. Tsitsa Project Report, June 2019. Rhodes University/DEFF.

Reporting Frequency: Annually
Individual(s) responsible: Biophysical Monitoring Group (Bennie, Nicholaus).
Location: See map, site names and coordinates of river monitoring sites in Huchzermeyer, N., Schlegel, P. & vd Waal, B. (2019). *Biophysical Monitoring Methods in the Upper Tsitsa River Catchment (T35 A-E)*. Tsitsa Project Report, June 2019. Rhodes University/DEFF. There are currently 9 flow loggers in T35 A-E and a further 4 in T35 H-K.
DATA QUALITY ISSUES
Known Data Limitations: Baseflow varies spatially and temporally and is influenced by several factors including geology, topography, climatic variations and human activities. The relationship between these factors and dry season baseflow is complex. Changes in baseflow therefore need to be understood with reference to the historical baseline for a particular catchment. The discharge measurements at the natural river sites are less accurate than those at the engineered DWS gauging stations because the river cross-sectional profile can change over time and some of the logger placings are less sensitive to low flows (loggers were installed to target high flows when sediment transport peaks). However, the data are considered sufficiently accurate, and the gauging station data are used as data controls for the other sites. A potential data limitation is the lack of maintenance budget for the DWS stations, which threatens their long-term viability and data quality. There are some data gaps in the DWS record
Dates of Previous Data Quality Assessments, methods and name of reviewer:
Dates of Future Data Quality Assessments *(optional)*:
BASELINE
Baseline timeframe *(optional)*: Historical baseflow time series from DWS gauges in the catchment (2 current gauging stations: T3H006 (Tsitsa at Qumbu T35K) from 1951 to present and T3H009 (Mooi at Maclear T35C) from 1964. Data from the current monitoring sites are available from 2015 onwards. Details in: Huchzermeyer, N., Schlegel, P. & vd Waal, B. (2019). *Biophysical Monitoring Methods in the Upper Tsitsa River Catchment (T35 A-E)*. Tsitsa Project Report, June 2019. Rhodes University/DEFF.
CHANGES TO INDICATOR
Changes to indicator:
Other Notes *(optional)*:
THIS SHEET LAST UPDATED ON: 13 January 2020

Testing the indicator

The baseflow indicator was tested by using the annual minimum monthly flows for the Tsitsa at Xonkonxa (T3H006; T35K) that has a flow record from 1952 (Figure 7). Unfortunately the flow data series has several gaps and the rating curve was recalibrated around 1983, resulting in higher low flow volumes pre 1980. According to Retha Stassen (experienced hydraulician) the data before 1980 should not be used for trend analysis due to the update in the rating curve around 1980 due to handover to DWS.

The modelled natural minimum monthly flows from the WR2012 database was kindly extracted and made available by Retha Stassen. It is clear that the observed flows are lower than the natural flows, possibly due to degraded ecological infrastructure and abstractions. The Eflows requirement for drought conditions prescribes a baseflow of 1.6 $m^3.s^{-1}$ (Rapid Reserve study; low to medium confidence; DWS Report No: P WMA 12/T30/00/5314/17). This requirement (that is considerably less than the maintenance year base flow (4.3 $m^3.s^{-1}$)) is often **not** met and raises concerns around the risk of failure to the socio-ecological system.

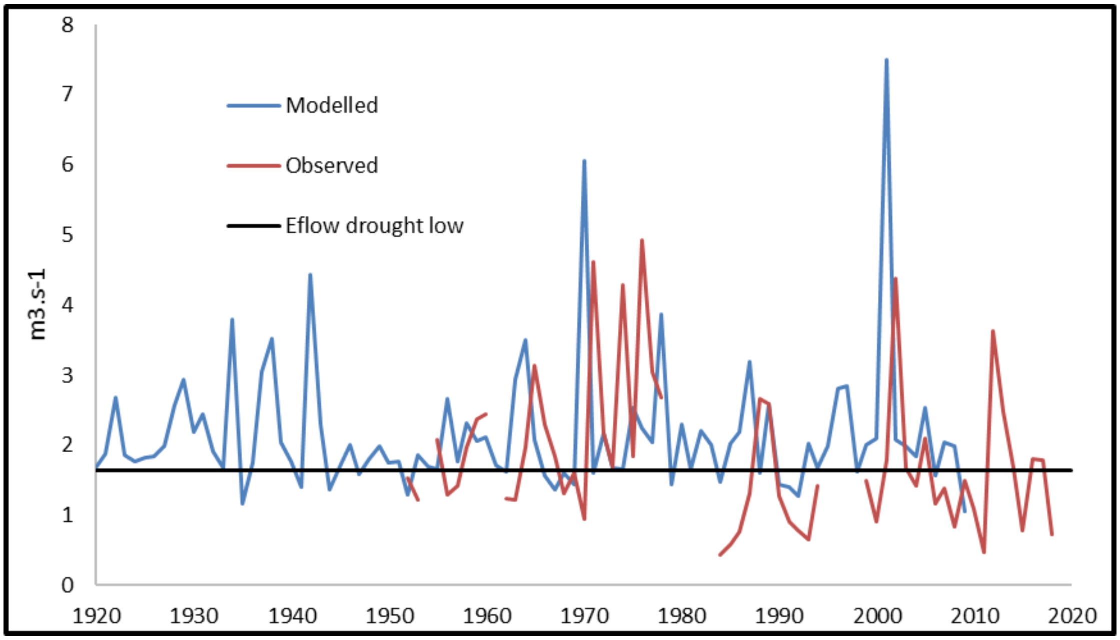


FIGURE 7: MODELLED AND OBSERVED MINIMUM ANNUAL MONTHLY FLOW DATA FOR THE TSITSA AT XONKONXA. THE EFLOW FOR DROUGHT LOW FLOWS (HIGHRISK OF FAILURE PREDICTED FOR SOCIOECOLOGICAL SYSTEM) IS INDICATED BY THE BLACK HORIZONTAL LINE

5.3. Grassland condition

Tsitsa Project Indicator Reference Sheet
Name of Result Measured (impact, outcome, output, process): Outcome
Name of Indicator: Grassland condition
DESCRIPTION
Precise Definition(s): Grassland condition including dominant grass species, average biomass, veld condition and grazing capacity.
Type of indicator: Quantitative
Unit of Measure: Grass species composition and % occurrence, grass average biomass ($kg.ha^{-1}$), Veld Condition Assessment score, grazing capacity (ha per large stock unit or LSU).
Integration with other indicators: In the Biotrack project (2019), trends in rangeland performance and forage production over the past two decades are evaluated at five grassland sites comprising a range of land tenure types, management regimes and condition classes in the T 35 A-E quaternary catchments. Time series of Leaf Area Index (LAI), Normalized Difference Vegetation Index (NDVI), and Net Photosynthetic Activity (PsnNet), analogous to net primary production are derived from

surface reflectances retrieved by the MODIS satellite sensor and analysed using the BFAST package in R. Thematic maps of primary productivity are generated for the entire sub-catchment area, and long-term MODIS estimates of forage availability used to calculate grazing capacities at each of the five study sites. Three of the Biotrack sites overlap with the Tsitsa Project's grassland condition monitoring sites. Can be linked to Alien Vegetation extent. Healthy grasslands should reduce the amount of suspended sediment entering the river system.
Disaggregated by: Site
Rationale or Justification for indicator: The Tsitsa catchment is dominated by grassland vegetation (Mucina & Rutherford, 2006). Grasslands are an important resource for the people living within the catchment. However, grasslands in the catchment are characterised by many symptoms of veld degradation with the most prominent being large-scale erosion and the encroachment of alien vegetation. One of the driving forces behind this degradation is the lack of grazing and fire management systems. To assess the current grassland condition, monitoring sites were chosen that represent different land-uses, geology, elevations and vegetation types. Phase 1 of the grassland condition assessment is focused in the traditional council areas.
PLAN FOR DATA COLLECTION
Data Source: Vegetation monitoring along 8 marked permanent transects.
Method of data collection: Species composition: Whilst laying out the tape measure all plant species within visible distance are identified and noted (including the presence, abundance and type of forb species and woody vegetation). At every meter along the transect, the closest grass species is identified and noted. These can then be used as indicators for veld condition and to monitor change in species composition over time. **Biomass method:** A disk pasture meter is used to get readings of disc pasture meter height along the known transect. Fifty readings are taken along the transect. The mean disc pasture meter height is used to calculate the standing crop (kg.ha^{-1}). A calibration table of mean disc pasture meter height vs. equivalent standing crop is used. In turn the grazing capacity can be calculated using methods set out by Van Oudtshoorn (2015). **Veld Condition Assessment**: This method evaluates multiple criteria over a broader spectrum to give an indication of overall veld condition and health. Observations and estimations on soil health, productivity and general ecology are used to get an overall veld condition score for each site. It is important to note that this score is subject to the views of the person conducting the assessment. **Photographs** are also taken at each veld monitoring point. The photographer stands over the cairn and faces the direction of the transect. If the transect branches in an 'L' shape, then a second set of photographs is taken where the transect changes direction (this distance is noted) and the position can be relocated by measuring the required distance from the cairn with a tape measure. Photographs are taken in both landscape and portrait layout using a digital camera. Repeat photographs can be taken from the same point in the same direction (fixed point) at the same time of year (preferably once in summer and once in winter). This can be used to monitor available fodder and change in vegetation structure over time.
Reporting Frequency: Annually
Individual(s) responsible: Biophysical Monitoring Group (Nicjolaus)
Location: 8 Grassland monitoring sites chosen to be representative based on various criteria (vegetation type, geology, average Normalized Difference Vegetation Index value for the growing/rainy season, location, elevation, topography, slope and aspect). Four sites are situated on abandoned cultivated land. See details in Huchzermeyer, N., Schlegel, P. & vd

Waal, B. (2019). *Biophysical Monitoring Report 1 of the Upper Tsitsa River Catchment (T35 A-E)*. Tsitsa Project Report, August 2019. Rhodes University/DEFF. Each site was marked with a cairn at the start point of the veld monitoring transect. Cairns consist of 50 centimeters of black irrigation pipe filled with cement that is buried in the ground with only the top 10 centimeters exposed. Additionally, rocks were packed around the cairn. Each cairn was marked with a GPS point for future reference.
DATA QUALITY ISSUES
Known Data Limitations: The veld condition scores are focused on the grazing potential of each site and not necessarily the diversity of plants present. Forbs, for example, are important for biodiversity and ecology as many are legumes that fix nitrogen which improves the soils and grasses around them. There is a significant difference between the Biotrack (2019) and the Tsitsa Project' estimated grazing capacity values. It is important to note that the values were estimated at different scales and should be interpreted together with the context of each site and report. See Huchzermeyer, N., Schlegel, P. & vd Waal, B. (2019). *Biophysical Monitoring Report 1 of the Upper Tsitsa River Catchment (T35 A-E)*. Tsitsa Project Report, August 2019. Rhodes University/DEFF (Table 14).
Dates of Previous Data Quality Assessments, methods and name of reviewer:
Dates of Future Data Quality Assessments *(optional)*:
BASELINE
Baseline timeframe *(optional)*: Results of the first assessment are given in Huchzermeyer, N., Schlegel, P. & vd Waal, B. (2019). *Biophysical Monitoring Report 1 of the Upper Tsitsa River Catchment (T35 A-E)*. Tsitsa Project Report, August 2019. Rhodes University/DEFF. Baseline condition of sites (see Table 12 in above-mentioned report): Sites on abandoned cultivated lands where the soil structure was disturbed and had not had enough time to recover had a very poor veld condition (Sites 4 and 8). These sites were heavily utilized and had low biomass values (> 960 kg.ha^{-1}) and only poor grazing grass species were present with large areas of bare ground. Sites classified as having a poor veld condition (Site 1, 2, 5 and 6) were heavily grazed with biomass ranging from 1 000–2000 kg.ha^{-1} and less bare ground visible than in the very poor condition sites. Sites 3 and 7 were in a moderate condition with good grass cover and minimal bare ground. Many of the sites had nowhere near the amount of biomass required to benefit from prescribed burning. Up to 4.5 times the amount of biomass would be needed before prescribed burning should be considered (4 000 kg.ha^{-1} or more). All grazing capacities were considerably lower than the average long-term grazing norms for the grassland biome provided by DAFF, which are 4–6 Ha/LSU.
CHANGES TO INDICATOR
Changes to indicator:
Other Notes *(optional)*:
THIS SHEET LAST UPDATED ON: 13 January 2020

Initial results

Table 5 summarises the veld condition for each site and includes dominant grass species, biomass, veld condition and grazing capacity. The veld condition scores are focused on the grazing potential of each site and not necessarily the diversity of plants present. Forbs, for example, are important for biodiversity and ecology as many are legumes that fix nitrogen which improves the soils and grasses around them.

Sites classified as having a very poor veld condition (Site 4 & 8) occur on abandoned cultivated lands were the soil structure has been previously disturbed and not given enough time to recover. These sites are heavily utilized and have low biomass values (> 960 kg.ha^{-1}) and only poor grazing grass species are present with large areas of bare ground. These sites are also located on the mudstones of the Elliot and Molteno geological formation. These mudstones are highly erodible particularly when the vegetation cover is inhibited.

Sites classified as having a poor veld condition (Site 1, 2, 5 & 6) are heavily grazed with biomass ranging from 1 000-2 000 kg.ha^{-1}. Higher biomass values are present because the sites are located in lower gradient areas where water accumulates stimulating plant growth (e.g. close to wetlands, on alluvial deposits next to rivers or mid-slopes). There is less bare ground visible than in the sites classified as having a very poor veld condition.

Two sites were classified as having a moderate veld condition (Site 3 & 7). Site 3 is located in a managed grazing camp on a private farm and exhibits grasses that provide good grazing despite lower levels of grass biomass than other sites (1 592 kg.ha^{-1}). Site 5 is located on a valley bottom close to a wetland and exhibits the highest biomass of all the sites (2 667 kg.ha^{-1}). Both sites exhibit good grass cover with minimal bare ground and occur at altitudes of greater than 1 350 meters above sea level.

Biomass readings of 4 000 kg.ha-1 or more exhibit high biomass and only then would they benefit from a prescribed burning. Many of the sites are nowhere near this goal for biomass requiring up to 4.5 times the amount of biomass before pre-scribed burning should be considered. Overgrazing is commonly not a function of intensity but rather a function of frequency. Because the catchment is dominated by mudstones that are highly erodible it is important to maintain healthy vegetation cover throughout the catchment. All the sites would benefit by prolonged rest periods to allow for the stabilization of grass and other important plant population through re-growth and full seed production.

TABLE 5: SUMMARY TABLE OF VELD CONDITION, GRASS SPECIES AND GRAZING CAPACITY AT EACH VELD MONITORING SITE

Veld monitoring site	Number of grass species	Dominant grass and % occurrence	Average disc-pasture meter height (cm)	Average biomass (kg.ha^{-1})	Veld condition score (20=very poor; 80=very good)	Grazing capacity (ha/ large LSU)
1	8	*Sporobolus africanus (50%)*	4.4	1 392	33 Poor	7.9 Poor
2	5	*Sporobolus africanus (32%)*	6.0	1 903	44 Poor	5.9 Poor
3	8	*Themeda triandra (48%)*	5.0	1 592	48 Moderate	5.3 Moderate
4	8	*Sporobolus africanus (76%)*	3.2	958	21 Very Poor	12.6 Poor
5	8	*Digitaria ternata (36%)*	6.6	2 079	38 Poor	6.8 Poor
6	10	*Sporobolus africanus (36%)*	3.6	1 108	30 Poor	8.5 Poor
7	5	*Eragrostis plana (44%)*	8.8	2 667	49 Moderate	5.3 Moderate
8	7	*Sporobolus africanus (46%)*	3.0	881	21 Very poor	12.6 Poor

5.4. Landscape function

Tsitsa Project Indicator Reference Sheet
Name of Result Measured (impact, outcome, output, process): Outcome/Impact
Name of Indicator: Landscape function
DESCRIPTION
Precise Definition(s): Biophysical landscape functioning measured in terms of soil stability, water infiltration, nutrient cycling, vegetation structure and habitat quality for fauna.
Type of indicator: Quantitative and qualitative
Unit of Measure: Landscape Function Analysis (LFA) chronosequences
Integration with other indicators: LFA provides a finer-scale assessment of landscape "integrity" and functioning than dry season baseflow and suspended sediment. It complements the grassland condition indicator but is more integrative because it includes abiotic factors such as soil stability, water infiltration and nutrient cycling.
Disaggregated by: Site
Rationale or Justification for indicator: Landscape Function Analysis (Tongway & Hindley, 2004) is a monitoring procedure that uses quickly determined field indicators to assess the functional status of rangelands. It provides an integrated measure, at the hillslope and plot scales, of biogeochemical functioning and the feedback processes that regulate vegetation structure, composition and function in the long term. Even when plant cover is very low or absent, the data reflecting the residual landscape function can still be discerned by LFA.
PLAN FOR DATA COLLECTION
Data Source: Landscape Function Analysis along 8 marked permanent transects.
Method of data collection: LFA comprises three modules — a conceptual framework, a field methodology and an interpretational framework — and is intended to generate chronosequences of data. The conceptual framework focuses on the processes that regulate the spatial movement and use of water, topsoil and organic matter in the landscape. The field methodology uses simple, visual indicators closely related to a range of physical, chemical and biological processes, taking only a few seconds per indicator to assess in the field after training. Observations of system dynamics are made in two spatially nested scales ('hillslope' and 'patch'). A patch is an area on a hillslope where scarce, vital resources tend to be accumulated. A software template generates a series of tables containing data at both scales. The interpretational framework is based on a sigmoidal response surface linking the lowest and highest functional examples of a given landscape type across a stress/disturbance gradient. It facilitates the identification of target values for rehabilitation and the propinquity of monitored sites to a critical threshold distinguishing 'sustainable' from 'unsustainable' management/climate combinations (Tongway & Hindley, 2004). 'Fragile' site types can be identified and subjected to more careful or more frequent assessment than sites shown to be 'robust' under the prevailing management regime.
Reporting Frequency: Annually
Individual(s) responsible: Biophysical Monitoring Group and/or Grass & Fire COP
Location: Same sites as Grassland condition assessment
DATA QUALITY ISSUES
Known Data Limitations: The LFA values need to be interpreted in the whole landscape and land-use context to make the most use of their information potential.

LFA is specifically focused on biophysical system functioning. It does not provide answers as to whether particular rangeland management practices are socially acceptable or desirable. This needs to be determined separately together with stakeholders and factored into the LFA analysis framework.
Dates of Previous Data Quality Assessments, methods and name of reviewer:
Dates of Future Data Quality Assessments *(optional)*:
BASELINE
Baseline timeframe *(optional)*:
CHANGES TO INDICATOR
Changes to indicator:
Other Notes *(optional)*:
THIS SHEET LAST UPDATED ON: 13 January 2020

Initial results

The first LFA analyses will take place in April 2020 at the veld monitoring sites. However, the results of a basic landscape analysis reflects in the Veld condition score reported in the Grassland condition section 5.3.

5.5. Woody invasive species cover

Tsitsa Project Indicator Reference Sheet
Name of Result Measured (impact, outcome, output, process): Outcome
Name of Indicator: Woody invasive species cover
DESCRIPTION
Precise Definition(s): Extent of woody invasive alien species in terms of area covered.
Type of indicator: Quantitative
Unit of Measure: Hectares (and mapped location of patches)
Integration with other indicators: Grassland condition (reduced with more alien vegetation); Dry season baseflow (alien veg takes up a lot of water; decrease in alien veg should allow for a more stable and prolonged winter baseflow)
Disaggregated by: Can be disaggregated by mini-catchments/priority nodes
Rationale or Justification for indicator: The Tsitsa Catchment (T35) falls within the grassland terrestrial biome. The grassland biome covers a large area and includes some of the most important water source areas in the country (van Wilgen *et al*. 2008). SANBI (2013) state that grassland ecosystems provide many essential ecosystem services which are underpinned by a rich biodiversity. However, the integrity of the grassland biome is threatened by the encroachment of alien vegetation. Poor grassland management,

particularly over-grazing and the incorrect application or exclusion of fire, leads to infestation by woody invasive alien species (such as Australian wattle, *Acacia* species), as well as shrubs (such as bramble, *Rubus* species). As the ecosystem becomes negatively affected by poor management, the natural resilience to infestation by invasive alien species is reduced and this can ultimately lead to a complete modification of the grassland into a stand of woody invasive alien plants. Ideally, there should be no invasive alien species (or only very few) in a healthy grassland.

Detailed national data sets on the location of alien tree species and their coverage extent at a catchment scale are scarce. In order to separate indigenous vegetation from alien vegetation and to prioritise alien vegetation for clearing it is imperative to have a good overview of woody vegetation in the catchment (Huchzermeyer *et al*., 2018a). These alien vegetation stands can then be monitored to see if they are spreading into the surrounding landscape and if alien vegetation clearing initiatives are being successful.

PLAN FOR DATA COLLECTION

Data Source: RapidEye satellite imagery (5 meter resolution)/Aerial images if available for the year (25-50 cm resolution)

Method of data collection: Normalised Difference Vegetation Index (NDVI) analysis using RapidEye satellite imagery dated in a winter month when vegetation growth vigour for vegetation such as grasslands and wetlands is reduced making it easier to extract woody vegetation (maintains a higher growth vigour in winter). Woody vegetation NDVI values (0.4–0.8) are used to create polygons for woody invasive species, planted forests and indigenous forests (these need to be classified). The polygons are checked by overlaying them on digital aerial photographs (if available) and through ground-truthing. Changes in alien vegetation extent can be picked up by comparing the new woody vegetation polygons to the baseline alien vegetation polygons (Huchzermeyer *et al.,* 2018a). New polygons that don't overlap with Huchzermeyer *et al*. (2018a) need to be classified as alien vegetation or indigenous. This will help pick up new populations of alien vegetation.

Reporting Frequency: Annually for key nodes. 5 Yearly for greater catchment

Individual(s) responsible: Biophysical Monitoring Group (Nicholaus)

Location: Entire catchment

DATA QUALITY ISSUES

Known Data Limitations: Herbaceous and graminoid (non-woody) invaders can also have significant effects on the health of rangelands and in turn affect the livelihoods of stakeholders in the catchment, however these species are hard to identify in the landscape.

Dates of Previous Data Quality Assessments, methods and name of reviewer:

Dates of Future Data Quality Assessments *(optional)*:

BASELINE

Baseline timeframe (optional): Huchzermeyer, N.H., Schlegel, P.K. & van der Waal, B. (2018). Woody vegetation in Catchment T35 A-E: mapping and classifying the extent of woody vegetation with an emphasis on alien invasive species. Tsitsa Project: Mapping report.

A total of 37 dominant alien woody species were identified in Catchment T35 A-E of which 7 species (silver wattle, black wattle, green wattle, poplar, eucalyptus, pine and Mauritius thorn) were invading hillslopes, riparian zones and indigenous vegetation on a large scale. Approximately 51% of the area covered by alien woody vegetation occurs on hillslopes, 43% in the riparian zones and the remaining 6% are spreading from drainage lines, plantations, gardens and woodlots. 56% of the alien vegetation category was verified in the field. From the alien vegetation category verified in the field only 3% was noted to be actively used and harvested to such an extent that it was no longer spreading. This is particularly evident within close walking distance of villages. The main alien species are: silver, black and green wattles,

Mauritius Thorn, Eucalyptus spp., pines and poplars.
CHANGES TO INDICATOR
Changes to indicator:
Other Notes *(optional)*:
THIS SHEET LAST UPDATED ON: 13 January 2020

Initial baseline results

The following is taken from Huchzermeyer *et al.* (2018a). A total of 37 dominant alien woody species were identified in Catchment T35 A-E of which 7 species (silver wattle, black wattle, green wattle, poplar, eucalyptus, pine and Mauritius thorn) are invading hillslopes, riparian zones and indigenous vegetation on a large scale. Approximately 51% of the area covered by alien woody vegetation occurs on hillslopes, 43% in the riparian zones and the remaining 6% are spreading from drainage lines, plantations, gardens and woodlots. 56% of the alien vegetation category was verified in the field. From the alien vegetation category verified in the field only 3% was noted to be actively used and harvested to such an extent that it was no longer spreading. This is particularly evident within close walking distance of villages.

The main alien species in Catchment T35 A-E can be detailed as follows:

- **Silver wattle:** A total of 6 955 patches (uncondensed area of 5 502 ha). Of those 3 671 (3 326 ha) of the patches consist of 50 percent and above Silver wattle.
- **Black wattle:** A total of 280 patches (uncondensed area of 262 ha). Of those, 246 (239 ha) of the patches consist of 50 percent and above Black wattle.
- **Green wattle:** A total of 441 patches (uncondensed area of 222 ha). Of those, 243 (97 ha) of the patches consist of 50 percent and above Green wattle.
- **Black and Green wattle co-existing:** A total of 6 675 patches (uncondensed area of 5 398 ha).
- **Mauritius thorn:** A total of 60 patches (uncondensed area of 3.8 ha). However, there might be a higher abundance as they are difficult to identify off aerial photographs and commonly occur in drainage lines and gullies where remote sensing techniques are limited.
- **Eucalyptus species:** A total of 1 028 patches (uncondensed area of 1 293 ha) occur outside of the plantation areas. Of those, 331 (343 ha) of the patches consist of 50 percent and above Eucalyptus species.
- **Pine species:** There are a total of 228 patches (uncondensed area of 137 ha) occur outside of the plantation areas. Of those, 39 (21 ha) of the patches consist of 50 percent and above Pine species.
- **Poplar species:** A total of 917 patches (uncondensed area of 1 099 ha). Of those 190 (160 ha) of the patches consist of 50 percent and above of Poplar species.

In the grasslands of Catchment T35 IAPs pose a threat to rangeland functioning and extent (van Wilgen & Wilson, 2018). Large areas of degraded hillslopes and riverine habitat have been invaded by woody IAPs, for example, *Acacia mearnsii* (Black wattle), *Acacia decurrens* (Green wattle), *Acacia dealbata* (Silver wattle) *and Pinus patula* (Patula pine) (Clark, 2018; Huchzermeyer *et al.*, 2018a).

Clark (2018) conducted a future forecasting for IAPs in the Tsitsa Catchment. A simple horizon detection was undertaken to determine which IAPs are currently present and which additional IAPs may invade the

Tsitsa Catchment in the future. The following key points can be taken from Clark (2018) for the management of present and future IAPs in the Tsitsa Catchment:

- In terms of ecological impact and spatial extent, the most extensive species are most likely to be **Australian Acacias (*A. dealbata, A. mearnsii*, *A. decurrens*** and possibly ***A. melanoxylon*),**
- Other woody invaders comprising a significant threat to either water production or riparian functioning (notably *Pinus patula, Populus x canescens, Robinia pseudo-acacia* and *Salix* spp., but also likely *Cotoneaster* spp., *Gleditsia triacanthos, Eucalyptus* spp., *Melia azedarach*, *Populus deltoides, Pyracantha* spp., *Rosa rubig*inosa and *Rubus* spp.).
- Commercial timber species like *Pinus patula* are likely to continue invading the landscape.
- The presence and spread of ornamental species is likely to be associated with urban centers such as Maclear. It is important to assess nodes and factors of invasion such as:
    - Suburban gardens in towns (many ornamental species).
    - Main through roads acting as a disturbed corridor for linear spread.
    - Intentional introductions in urban areas, farmsteads, kraals and plantations.
    - An already degraded environment makes it easier for invasions to spread.
- Herbaceous and graminoid (non-woody) invaders **should not** be overlooked because they do not pose as great a risk on water abstraction as woody species. Herbaceous and graminoid species can be hard to identify in the landscape but can have significant effects on the health of rangelands and in turn affect the livelihoods of stakeholders in the catchment.
- The three South American tussock grasses introduced to South Africa – namely *Nassella neesiana* (Chilean Needle Grass), *N. tenuissima* (White Tussock) and *N. trichotoma* (Serrated Tussock) – and the rapidly spreading *Campuloclinium macrocephalum* (Pompom Weed), are considered as top priority for future catchment management.

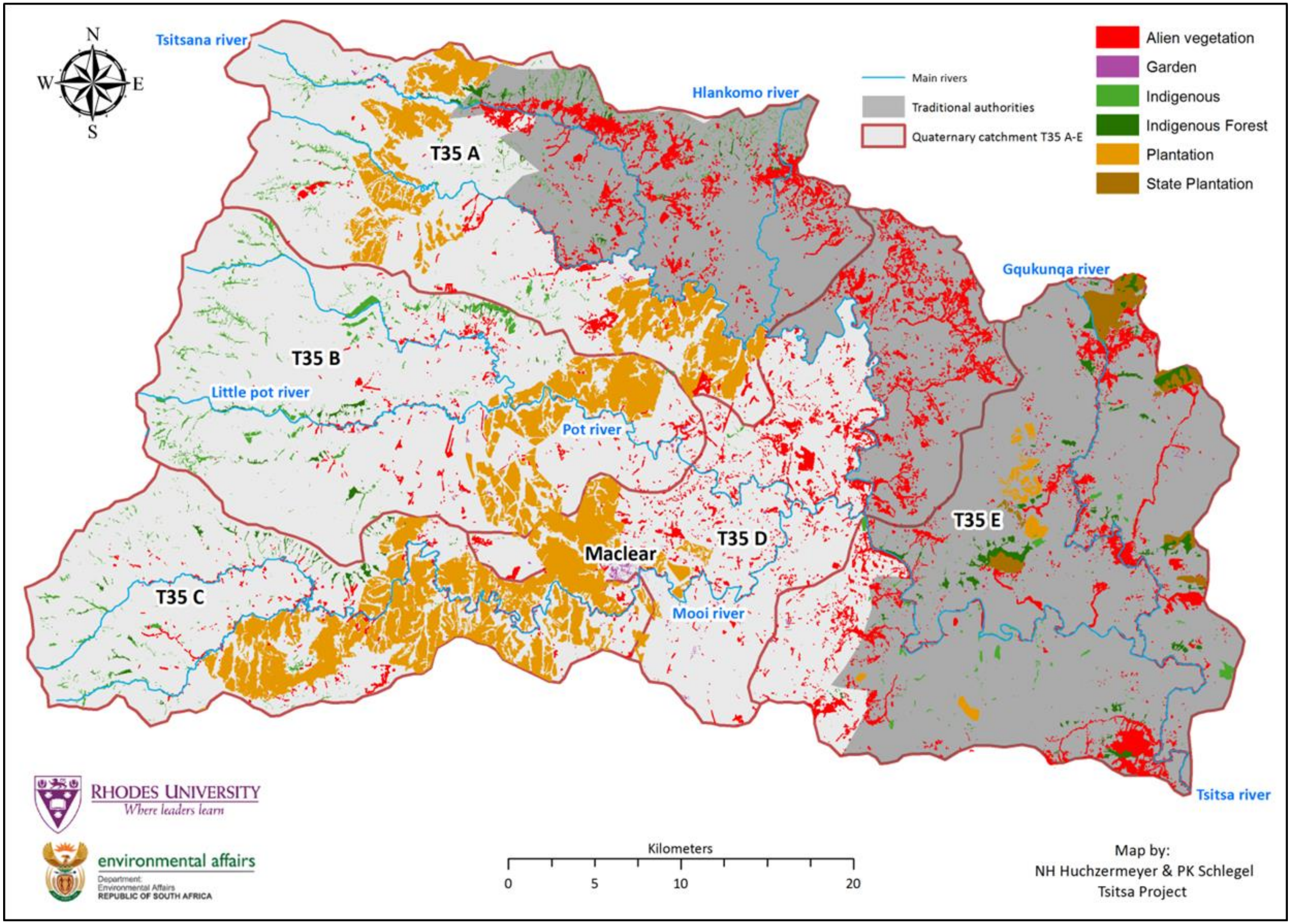


Figure 8: Mapped woody vegetation in Catchment T35 A-E showing alien vegetation extent (Huchzermeyer *et al.*, 2018a)

5.6. Suspended sediment concentration

Tsitsa Project Indicator Reference Sheet
Name of Result Measured (impact, outcome, output, process): Impact
Name of Indicator: Suspended sediment
DESCRIPTION
Precise Definition(s): Suspended sediment concentration (SSC)
Type of indicator: Quantitative
Unit of Measure: milligrams of sediment per litre of water (mg/l)
Integration with other indicators: Other quantitative data derived from laboratory analysis of the water samples are visual clarity, electrical conductivity (EC) and measured turbidity. These data are supplemented by the discharge data collected by the Solinst level loggers and rainfall data from the rain gauges installed throughout the catchment. A range of flow measurements and width- and depth-integrated SSC data is also collected by researchers to calibrate the single-point depth-integrated samples collected by the citizen technicians. The photographic evidence collected by the technicians provides a real-time indication of river stage and turbidity.
Disaggregated by: Site
Rationale or Justification for indicator: Suspended sediment fluxes and yields provide insight into the sources, magnitude, and dynamics of catchment soil erosion and loss (Bannatyne et al., 2017). In the Tsitsa catchment, with its highly erodible duplex soils and deep, dense gully networks, this indicator measures the integrated impact of all the various interventions aimed at reducing hillslope erosion through both active restoration and avoided degradation.
PLAN FOR DATA COLLECTION
Data Source: Sub-daily samples collected by a team of paid citizen technicians.
Method of data collection: Citizen technicians take routine samples each morning before 11h00 and each afternoon after 14h00, ideally at roughly 12-hourly intervals, using simple supplied equipment (see Bannatyne et al., 2017). These are depth-integrated point samples. Since suspended sediment yield is dominated by flood events, there is a special protocol for flood sampling which is triggered by an observed rise in water levels. Specific sampling intervals derived for each monitoring site (based on flood duration predictions) allow 20 consecutive samples to effectively represent the hydrograph (including the recession limb) of those 'workhorse' floods that in a typical year move most of the suspended sediment. Citizen technicians also collect geo-referenced photographic, numerical and descriptive data using the customised Open Data Kit (ODK) forms loaded onto smartphones. Completed forms are saved by ODK Collect to the smartphone memory and, ideally, immediately transmitted to the receiving ODK Aggregate database using the cellular network (whereupon they are immediately available to researchers). Samples are collected and saved forms downloaded from the smartphones at 3-5 week intervals by a research administrator during routine visits to the citizen technicians' homes to provide support, resupply sampling equipment, and resolve any quality-control or performance issues as revealed by checking the ODK Aggregate database changes since the last visit. Laboratory analysis of SSC is done using an evaporation method (see Bannatyne et al., 2017). For visibly high sediment samples (> 200 ntu), the determination of SSC by settling, supernatant removal and oven evaporation is carried out in the original sample jars. Turbidity

is used as a surrogate in visibly low sediment samples (< 200 ntu). A relationship between turbidity-tested and evaporated results has been established for each site.
Reporting Frequency: Annually (data available every 3-4 months).
Individual(s) responsible: Biophysical Monitoring Group (Laura Bannatyne – in charge, Zanele - data collation and quality control, and the team of 7 citizen technicians who collect samples)
Location: See Figures 2 and 3 in Bannatyne et al. (2017). Design and implementation of a citizen technician–based suspended sediment monitoring network: Lessons from the Tsitsa River catchment, South Africa. *Water SA,* 43(3). The sampling campaign was designed in response to recommendations for the monitoring of discharge and suspended sediment (Le Roux et al., 2015), to determine the relative contributions of the sub-catchments to the yield of the Tsitsa River at the site of the Ntabelanga Dam, and to assist with the prioritisation of community-based land restoration interventions. At reach scale, the monitoring sites are located within easy walking distance of dwellings, and typically feature a safe bank access point, bedrock for the attachment of a pressure transducer, and a stable profile to allow the research team to undertake periodic flow ratings.
DATA QUALITY ISSUES
Known Data Limitations: The size of the Tsitsa catchment means that the sediment monitoring sites are distant from each other and from specific land rehabilitation sites, so it may be difficult to connect the impact of land rehabilitation interventions to monitored changes in SS levels within the project period. Suspended sediment data collected by any means lies at best within a 20% error margin, and typically outside that margin (Bannatyne et al., 2017).
Dates of Previous Data Quality Assessments, methods and name of reviewer:
Dates of Future Data Quality Assessments *(optional)*:
BASELINE
Baseline timeframe *(optional)*: Short-term, calendar-based studies have correlated catchment conditions to sediment input to channels (Gordon et al., 2013) and established baseline water quality conditions including levels of suspended sediment (Madikizela and Dye, 2003). Catchment sediment yields have been modelled (Le Roux et al., 2015), but there is uncertainty attached to the results, which differ considerably from those of a study that incorporated dam sedimentation rates (Msadala, 2010). Initial results from the sediment monitoring by citizen technicians can be used as a baseline (Bannatyne et al., 2017).
CHANGES TO INDICATOR
Changes to indicator:
Other Notes *(optional)*:
THIS SHEET LAST UPDATED ON: 13 January 2020

Initial results

The following initial results are from the **Briefing note compiled by:** Laura Bannatyne and Dr Bennie van der Waal **Date**: 11/07/2018)

The monitoring sites are ranked from lowest to highest median SSC in Table 6**.** The median SSC values are illustrated spatially in Figure 9**.**

TABLE 6: SSC RECORDED AT MONITORING SITES IN THE TSITSA RIVER CATCHMENT

Monitoring site (ranked low to high SSC)	SSC mg/liter			Data period end (from Dec 2015)	number of samples
	25%	**50%**	**75%**		
Little Pot (T35 B)	82	**125**	168	03/2017	192
Mooi (T35 C)	82	**134**	318	05/2017	245
Hlankomo (T35 A)	77	**137**	289	05/2017	428
Pot (T35 B)	143	**243**	442	10/2017	757
Tsitsana (T35 A)	135	**347**	1065	04/2017	739
Tsitsa at Qulungashe Bridge (T35 E)	129	**350**	927	10/2017	792
Tsitsa at Gorge (T35 D)	168	**375**	798	03/2018	1110
Tsitsa at Falls (T35 A)	199	**431**	803	09/2017	1003
Gqukunqa (T35 E)	322	**596**	1436	02/2018	1527

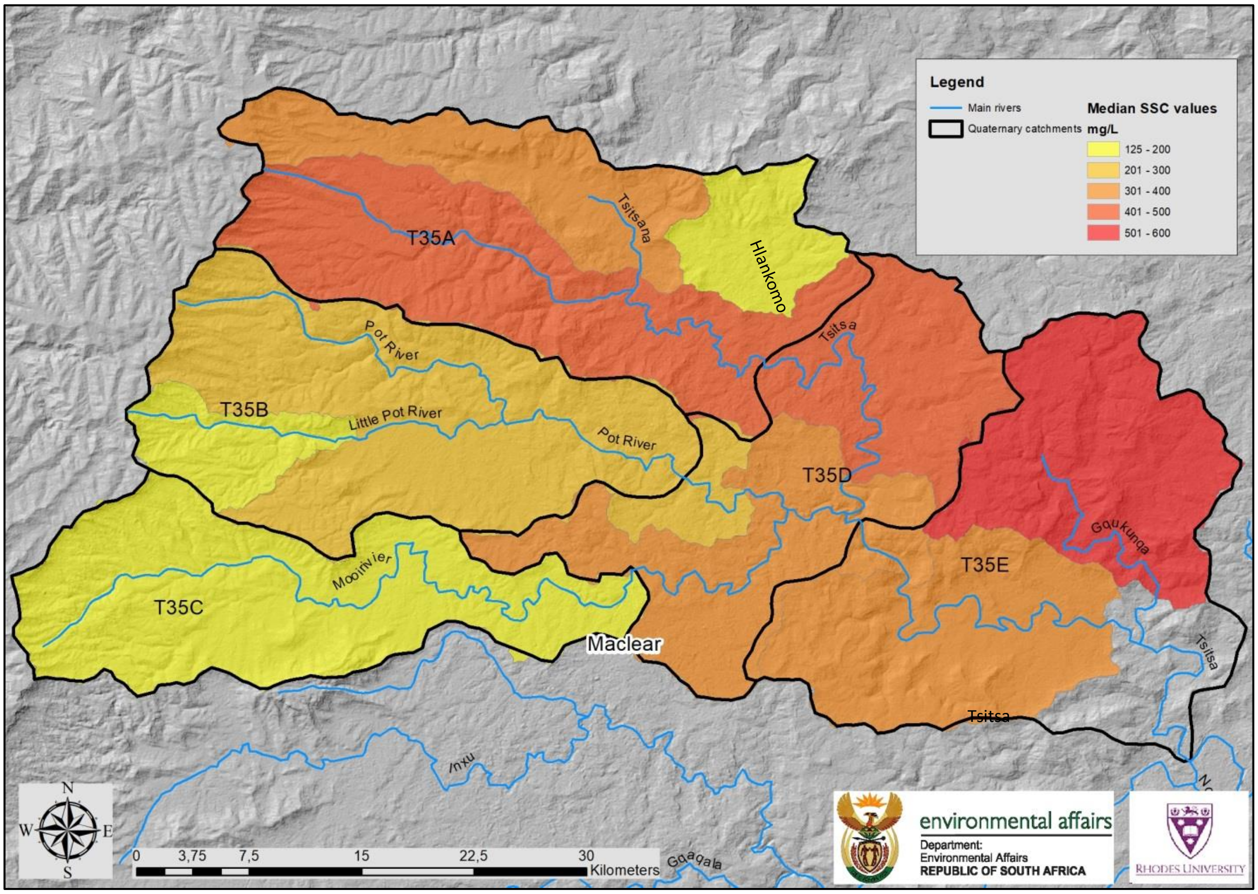


FIGURE 9: MEDIAN SSC RANKING IN CATCHMENT T35 A-E

The following can be concluded:

- The median SSC recorded for the Little Pot (T35 B), Mooi (T35 C), and Hlankomo (T35 A) Rivers is relatively low at < 150 mg/litre SSC.
- The median SSC recorded for the Pot River (T35 B), Tsitsana River (T35 A), Tsitsa River at Qulungashe Bridge (T35 E), and the Tsitsa River at the Gorge (T35 D) lies in the middle range for the area, between 200 and 400 mg/litre SSC.
- The median SSC recorded for the Tsitsa River at the Falls (T35 A and D) is relatively high at over 400 mg/litre SSC, whilst that for the Gqukunqa River (T35 E) is particularly high at nearly 600 mg/litre SSC.

Updates to these numbers will be available once the student (Laura Bannatyne) engages with final data processing.

6. SUSTAINABLE DEVELOPMENT GOALS

"The Sustainable Development Goals (SDGs) are the blueprint to achieve a better and more sustainable future for all. They address global challenges including poverty, inequality, climate change, environmental degradation, peace and justice. There are 17 interconnected goals which should be achieved by 2030" United Nations (2019).

Goal 15 is the most relevant to the biophysical monitoring and the work done by the Tsitsa Project can fit into these indicators. Therefore, by conducting an analysis using the international standards we can find out what the condition of the catchment is according to international goals.

Goal 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.**

Target 15.3: By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, droughts and floods, and strive to achieve a land degradation-neutral world

Indicator 15.3.1: Proportion of land that is degraded over total land area

- Sub-Indicators are trends in:
  - Land Cover
  - Land Productivity
  - Carbon Stocks

6.1. Assessing land degradation in Catchment T35 A-E using Trends.Earth for reporting on SDG 15.3.1

TRENDS.EARTH
tracking land change

Trends.Earth is a product of the Land Degradation Monitoring Project in partnership with Conservation International, Lund University, and the National Aeronautics and Space Administration (NASA), and is funded by the Global Environment Facility. It uses global data sources to assess and monitor land degradation at several scales and can be used to track achievement of the sustainable development goals including Target 15.3 (Trends.Earth, 2019). Trends.Earth computes the three sub-indicators (productivity, land cover and SOC) from Target 15.3 and integrates the results following the **one-out all-out** rule to come up with area of land degraded. Results are given at the end of each section below.

6.2. Land Cover

Land cover as defined by the United Nations (2019) refers to the observed physical cover on the Earth's surface and describes the distribution of vegetation units, water bodies and built infrastructure.

National land cover datasets are a key component of South Africa's environmental datasets. Changes in land cover can point to degradation (e.g. loss of key ecosystems) or landscape rejuvenation (such as the maintenance or gain of important and functional ecosystems).

There are three national land cover datasets for South Africa conducted in 1990, 2013/14 & 2018 and are managed by the Department of Environment, Forestry & Fisheries (DEFF). The 1990 & 2014 land cover datasets were classified from Landsat imagery and the 2018 land cover was classified from Sentinel 2 imagery which is considered to be superior and more detailed than the Landsat imagery (reduced spatial, spectral and temporal characteristics)(Thompson, 2019). In order to support long-term environmental monitoring land cover change assessments have been set up by Geoterraimage SA (Thompson, 2019) for DEFF. Change assessments for both 1990 vs 2018 and 2013/14 vs 2018 were undertaken. During this process the land cover dataset legend/classes were simplified and standardised to a new format based on 20 classes (see Table 7). A full explanation of the class changes can be found in Thompson (2019).

It is important to note that the 2018 land cover dataset was generated to try repeat the 1990 and 2014 data content as accurately as possible. However, with the use of Sentinel 2 imagery and the resulting improvement of spatial, spectral and temporal characteristics the mapped detail of the 2018 dataset is improved. Therefore not all the differences between the 1990/2014 vs 2018 datasets are true changes in the landscape but can rather be attributed to improved interpretation and mapping quality (Thompson, 2019). The change data must therefore be treated with caution and the location of change should be interpreted with caution.

In addition the land cover datasets are done at a national scale and the results should therefore be interpreted with caution at a catchment scale. However the temporal trends are often representative of what is occurring in the landscape even if there is slight error in the spatial trends. Table 7 gives an overview of the changes in land cover in Catchment T35 A-E between 1990/2014 & 2018. The data was sourced from Thompson (2019).

The largest changes occurred to the grasslands (Table 7, Figure 12 & Figure 10) due to an increase in planted forests (evident in Figure 12). Other noteworthy changes of grasslands is into natural wooded land and thicket/dense bush (most likely alien vegetation) and into eroded and barren land. A positive change (possibly due to better mapping accuracy) is a change of grassland into wetlands. Loss of grasslands to eroded lands is particularly evident in the lower catchment (T35 E).

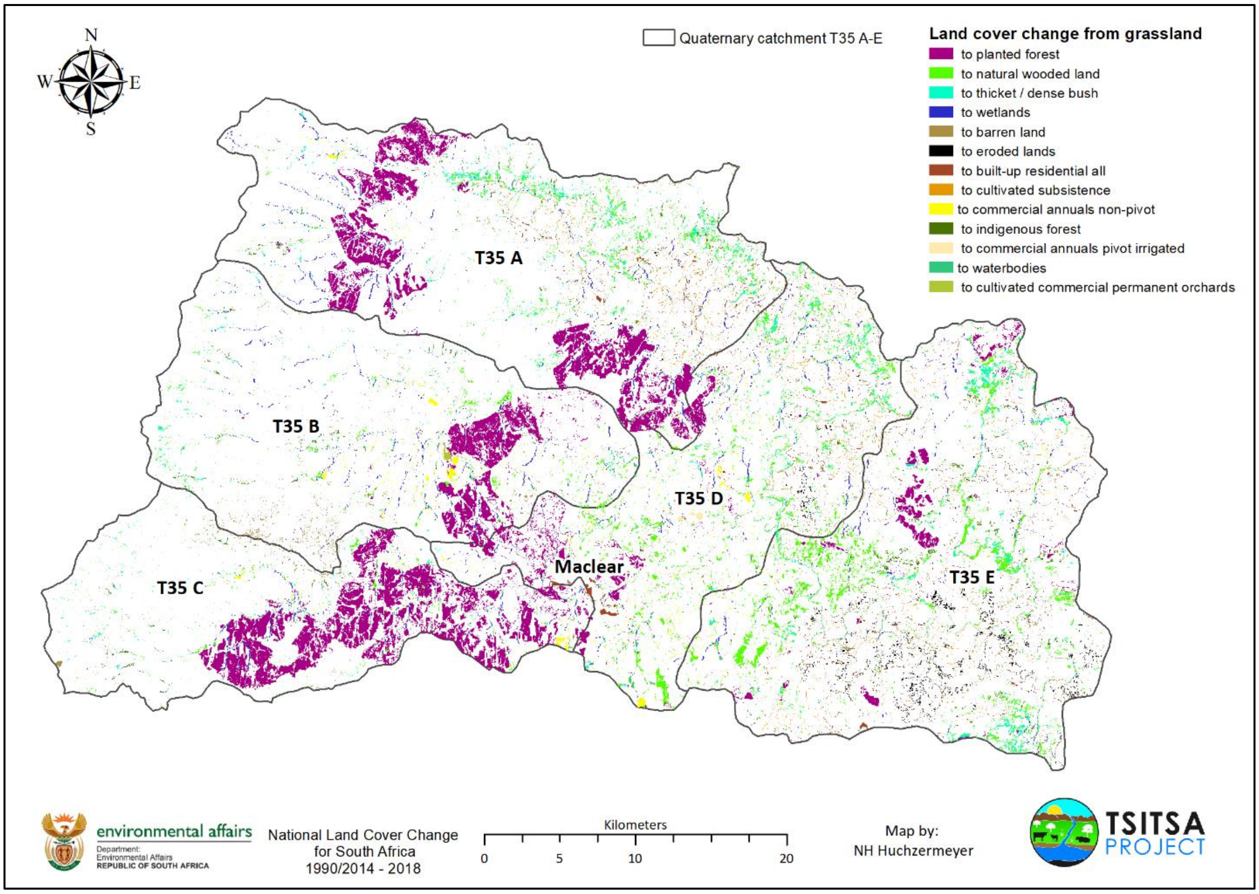
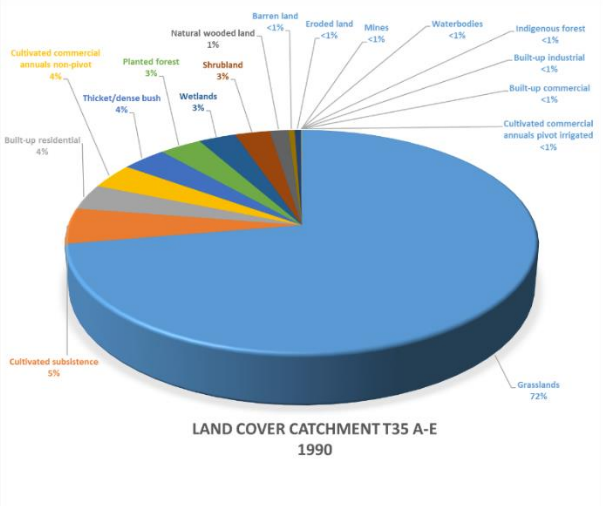


FIGURE 10: LOSS OF GRASSLAND IN CATCHMENT T35 A-E BETWEEN 1990 AND 2018

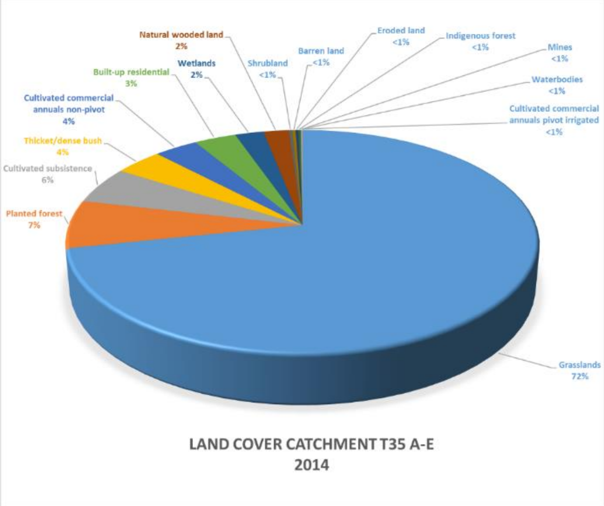
TABLE 7: LAND COVER CHANGE ASSESSMENT 1990/2014 VS 2018 (THOMPSON, 2019) FOR CATCHMENT T35 A-E SHOWING CHANGES IN THE STANDARDISED 20 CLASSES

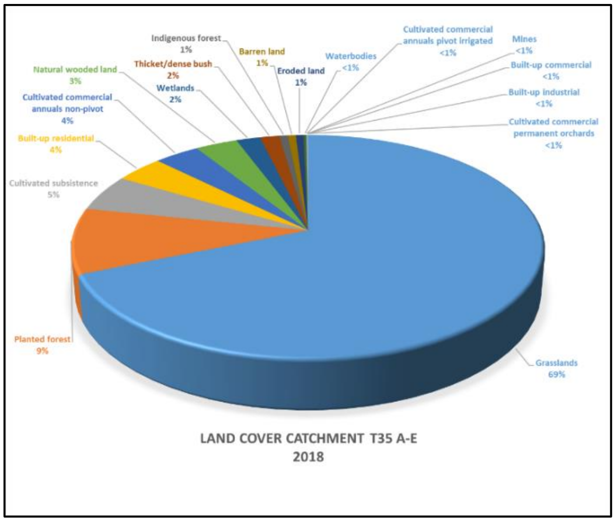
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
	2018	Indigenous Forest	Thicket / dense Bush	Natural Wooded Land	Planted Forest	Shrubland	Grasslands	Waterbodies	Wetlands	Barren Land	Eroded Lands	Cultivated Commercial Permanent Orchards	Cultivated Commercial Permanent Vines	Commercial Annuals Pivot Irrigated	Commercial Annuals Non-Pivot	Cultivated Subsistence	Built-up Residential	Built-up Smallholdings	Built-up Commercial	Built-up Industrial	Mines	**1990 / 2014**
1	Indigenous Forest	0.26	0.01	0.04	0.02	0.10	0.20	0.00	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**% unchanged**
2	Thicket / dense Bush	0.01	0.46	0.06	0.05	0.04	0.77	0.00	0.11	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	
3	Natural Wooded Land	0.01	0.52	0.15	0.04	0.20	2.09	0.00	0.13	0.11	0.00	0.00	0.00	0.00	0.03	0.01	0.04	0.00	0.00	0.00	0.00	<0.01% change
4	Planted Forest	0.00	0.14	0.19	2.51	0.13	6.19	0.00	0.00	0.23	0.01	0.00	0.00	0.00	0.07	0.00	0.01	0.00	0.00	0.00	0.00	
5	Shrubland	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01-0.09% change
6	Grasslands	0.03	2.17	1.04	0.65	2.17	60.25	0.00	1.33	0.32	0.24	0.00	0.00	0.00	0.22	0.26	0.12	0.00	0.00	0.00	0.01	
7	Waterbodies	0.02	0.01	0.00	0.01	0.10	0.02	0.04	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.1-0.9% change
8	Wetlands	0.00	0.08	0.02	0.04	0.01	0.74	0.00	0.98	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.01	0.00	0.00	0.00	0.00	
9	Barren Land	0.00	0.01	0.01	0.00	0.09	0.49	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.0-4.9% change
10	Eroded Lands	0.00	0.00	0.00	0.00	0.04	0.31	0.00	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
11	Cultivated Commercial Permanent Orchards	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	>5% change
12	Cultivated Commercial Permanent Vines	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
13	Commercial Annuals Pivot Irrigated	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	
14	Commercial Annuals Non-Pivot	0.00	0.01	0.01	0.03	0.00	0.26	0.00	0.04	0.00	0.00	0.00	0.00	0.00	3.22	0.00	0.02	0.00	0.00	0.00	0.00	
15	Cultivated Subsistence	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	4.84	0.04	0.00	0.00	0.00	0.00	
16	Built-up Residential	0.00	0.01	0.00	0.01	0.01	0.30	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	3.45	0.00	0.00	0.00	0.00	
17	Built-up Smallholdings	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
18	Built-up Commercial	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
19	Built-up Industrial	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
20	Mines	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	



Land Cover in the Tsitsa Catchment in 1990 was dominated by 72% grasslands, followed by 5% subsistence cultivation. Planted forests & wetlands made up 3% of the land cover respectively and eroded land <1%.

Land Cover in the Tsitsa Catchment in 2014 was still dominated by 72% grasslands followed by an increase in planted forests to 7% of the land cover. Cultivated subsistence made up 6%, wetlands 2% and eroded land <2%.





Land Cover in the Tsitsa Catchment in 2018 was dominated by 69% grasslands with an increase to 9% planted forest. Subsistence cultivation makes up 5%. Wetlands have reduced to 2% of the land cover and eroded lands have increased to 1%.

FIGURE 11: PERCENTAGE OF LAND COVER CLASSES IN CATCHMENT T35 A-E IN 1990, 2014 & 2018

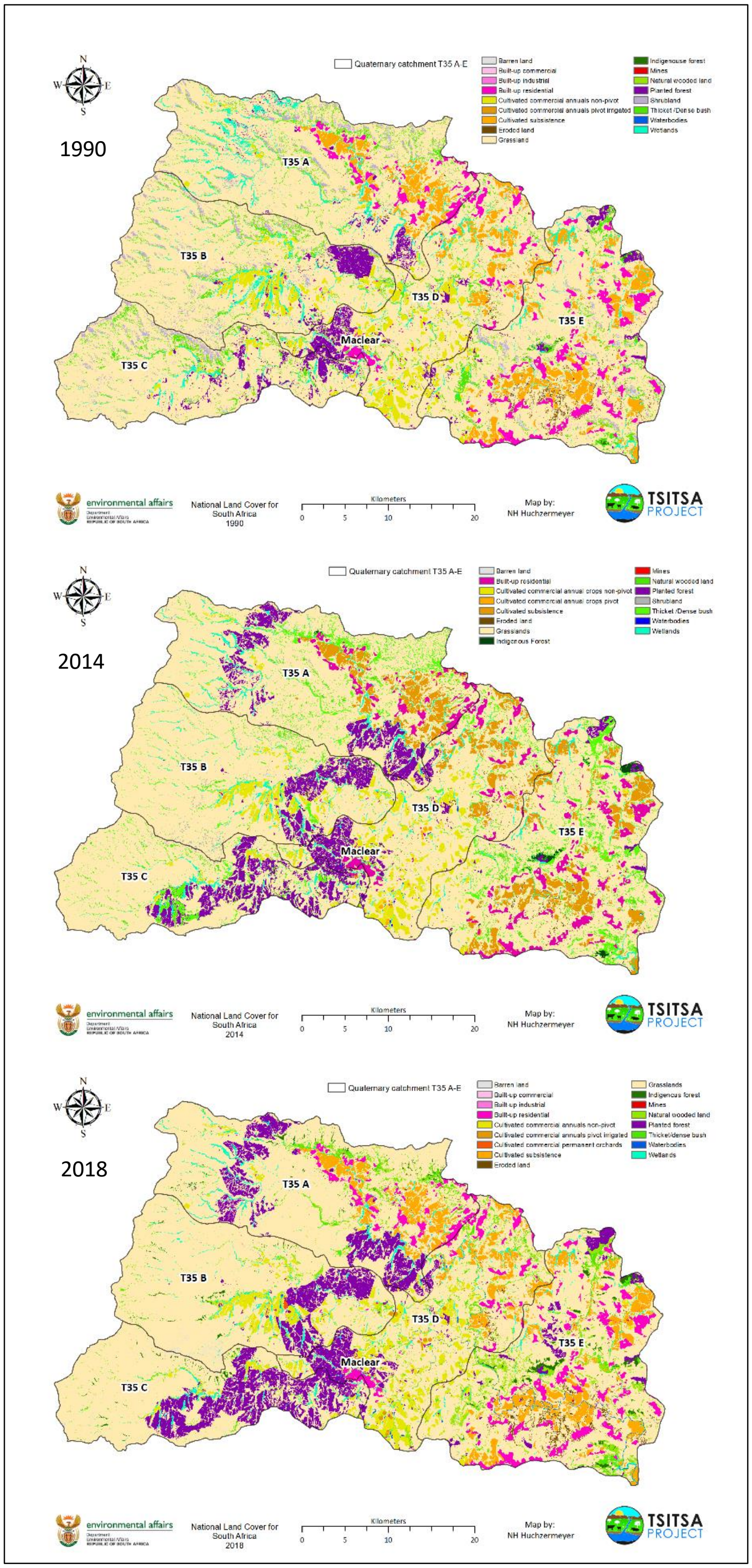


FIGURE 12: MAP OF LAND COVER IN CATCHMENT T35 A-E IN 1990, 2014 & 2018 (SOURCE GEOTERRAIMAGE)

6.2.1. Land cover results from Trends.Earth

The land cover data presented in section 6.2 were used to assess the changes in land cover in Trends.Earth. The 1990 land cover dataset was used as the start year and the 2018 dataset was used as the end year. The South African Land Cover dataset was reclassified to fit the 7 classes needed for the Trends.Earth analysis (Figure 13).

Setup aggregation of land cover data

Input code	Input class	Output class
Barren land	Barren land	Other land
Built-up co...	Built-up commercial	Artificial
Built-up ind...	Built-up industrial	Artificial
Built-up resi...	Built-up residential	Artificial
Cultivated c...	Cultivated commercial annuals non-pivot	Cropland
Cultivated c...	Cultivated commercial annuals pivot irrigated	Cropland
Cultivated s...	Cultivated subsistence	Cropland
Eroded land	Eroded land	Other land
Mines	Mines	Other land
Natural wo...	Natural wooded land	Tree-covered
Planted forest	Planted forest	Tree-covered
Waterbodies	Waterbodies	Water body
Wetlands	Wetlands	Wetland
Cultivated c...	Cultivated commercial permanent orchards	Cropland
Grasslands	Grasslands	Grassland
Indigenous ...	Indigenous forest	Tree-covered
Thicket/den...	Thicket/dense bush	Tree-covered

FIGURE 13: RECLASSIFICATION OF LAND COVER DATA TO FIT INTERNATIONAL DATASETS

According to the characteristics of the study area and the land degradation processes, land cover transitions can be identified that are either positive (improvement), negative (degradation) or remain stable. Figure 14 shows how the land cover transitions were set up in Trends.Earth for a grassland landscape. These are linked to the effects on land degradation (e.g. grasslands becoming encroached by tree-cover can be seen as a form of degradation).

Calculate SDG 15.3.1 Indicator (one-step)

Setup | Land Cover Setup | Define Effects of Land Cover Change | Area | Options

Land cover in target year

Land cover in initial year	Tree-covered	Grassland	Cropland	Wetland	Artificial	Bare land	Water body
Tree-covered	0	+	-	+	-	-	0
Grassland	-	0	-	0	-	-	0
Cropland	-	+	0	+	-	-	0
Wetland	-	0	-	0	-	-	0
Artificial	+	+	+	+	0	-	0
Bare land	0	+	0	+	0	0	0
Water body	0	0	0	0	0	0	0

Legend: Degradation (-) | Stable (0) | Improvement (+)

*The "Grassland" class consists of grassland, shrub, and sparsely vegetated areas (if the default aggregation is used).

FIGURE 14: TRANSITION CRITERIA FOR LAND COVER IN A GRASSLAND LANDSCAPE SUCH AS THE TSITSA CATCHMENT THAT WOULD EXHIBIT EITHER IMPROVEMENT, REMAIN STABLE OR SHOW DEGRADATION

Trends.Earth performs a land cover transition analysis to identify which pixels remained the same and which have changed to either a positive or a negative effect (Figure 15).

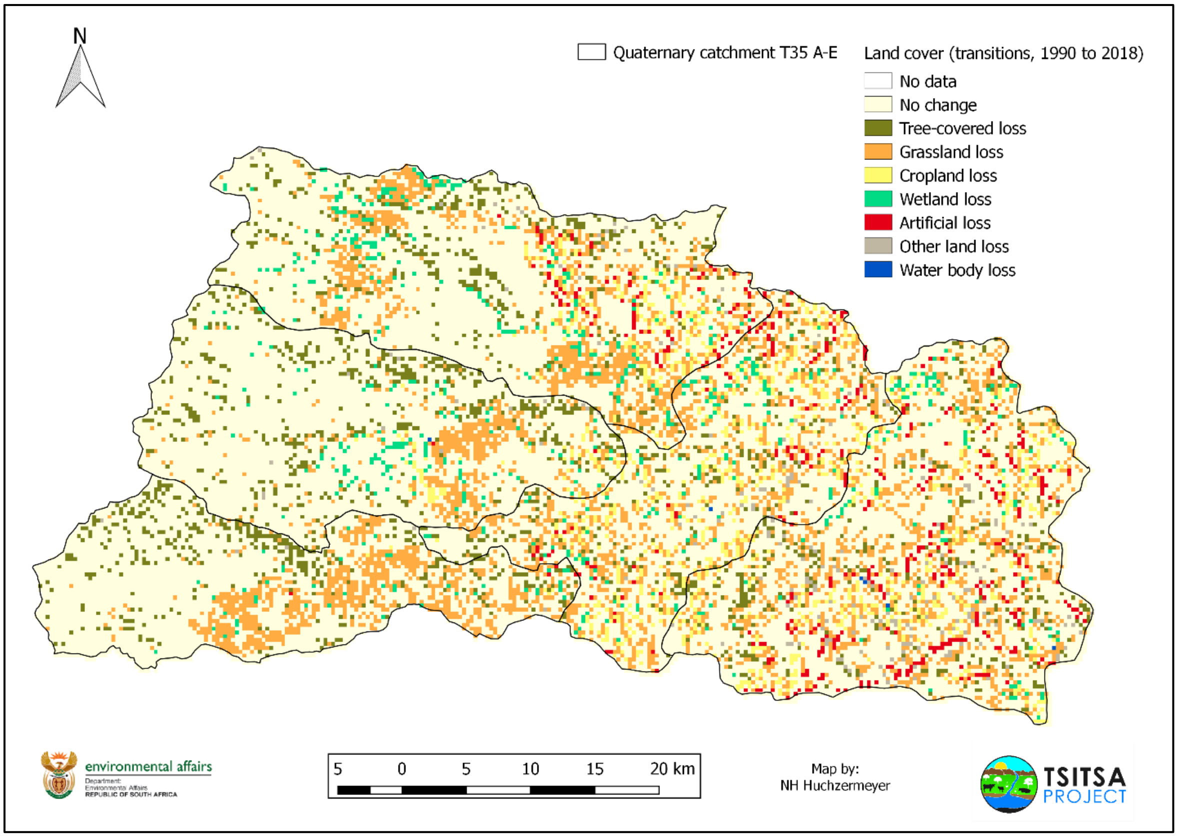


FIGURE 15: RESULTS OF A LAND COVER TRANSITION ANALYSIS USING TRENDS.EARTH

Table 8 & Figure 16 show the results of changes in land cover in Catchment T35 A-E and the resulting positive or negative effects thereof. Out of the total land area in Catchment T35 A-E 12% of the land cover has improved, 70% has remained the same and 18% has changed to a degraded state.

TABLE 8: SUMMARY OF CHANGE IN LAND COVER TO EITHER AN IMPROVED (POSITIVE) OR DEGRADED (NEGATIVE) LANDSCAPE FROM 1990-2018

	Area (sq km)	Total land area (%)
Total land area	2 004.4	100.00
Land area with **improved** land cover	236.1	11.78
Land area with **stable** land cover	1 409.9	70.34
Land area with **degraded** land cover	353.9	17.65
Land area with **no data**	4.5	0.22

Table 9 shows changes in land cover in each land cover class between 1990 (start year) and 2018 (end year. The greatest change is an increase in tree-covered areas, a decrease in grasslands and wetlands. The loss of grasslands is depicted by most of the degradation of land cover as seen in Figure 16. The increase in water bodies indicate the construction of smaller farm dams.

TABLE 9: LAND COVER CHANGE BY COVER CLASS

	Baseline area (sq. km)	Target area (sq. km)	Change in area (sq. km)
Tree-covered areas	223.49	307.42	83.92
Grasslands	1 451.66	1 372.82	-78.83
Croplands	178.13	184.01	5.87
Wetlands	61.65	39.15	-22.50
Artificial areas	70.69	73.37	2.67
Other lands	18.52	23.00	4.48
Water bodies	0.37	4.75	4.38
Total:	*2 004.52*	*2 004.52*	*0.00*

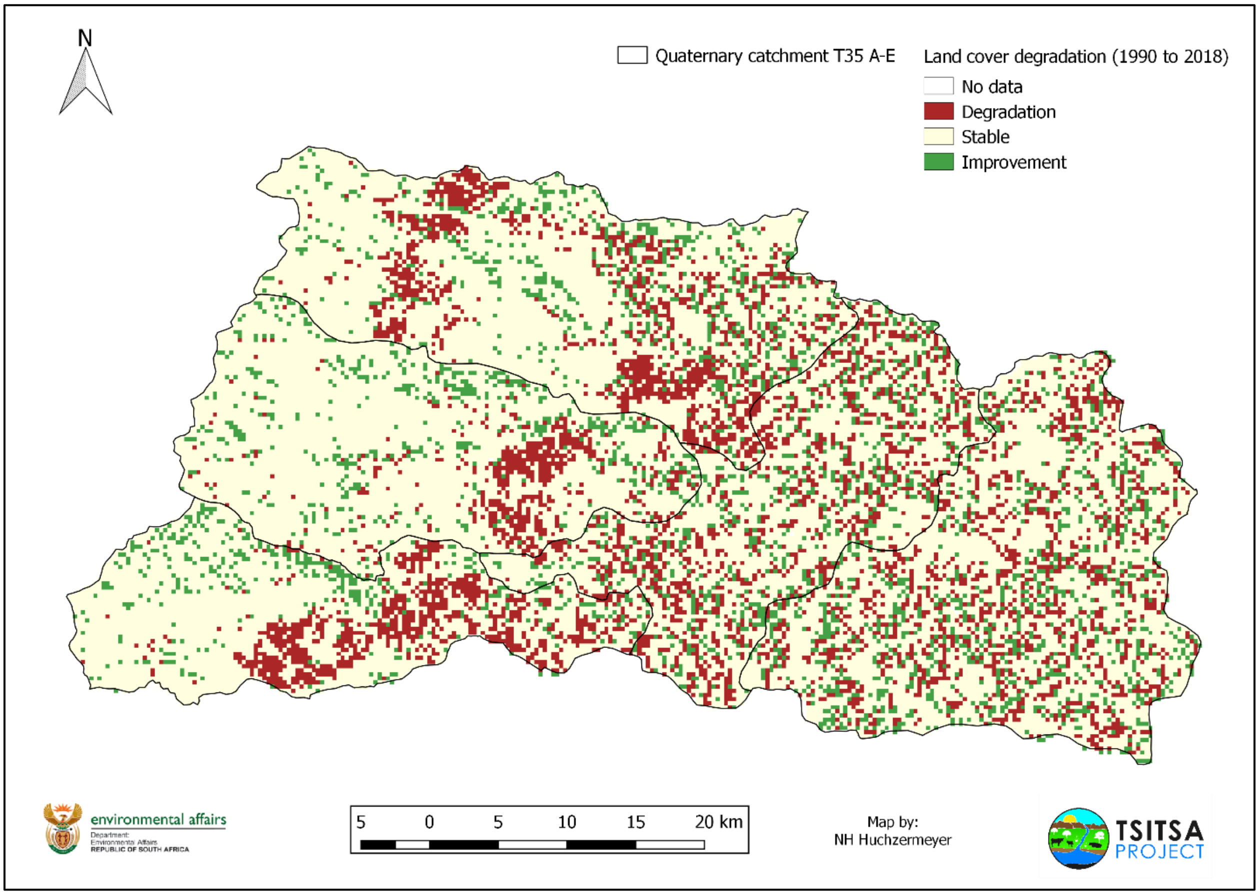


FIGURE 16: LAND COVER DEGRADATION AND IMPROVEMENT IN CATCHMENT T35 A-E BETWEEN 1990 AND 2018

6.3. Land productivity

Land productivity as defined by the United Nations (2019) refers to the total above-ground **net primary production (NPP)** which is defined as the energy fixed by plants subtracted by their respiration which equals the rate of biomass accumulations. This delivers a multitude of ecosystem services.

Moderate Resolution Imaging Spectroradiometer (MODIS) is an instrument installed on the Terra and Aqua satellites which pass over the entire earth's surface every one to two days (NASA, 2019). The MODIS satellite gathers data the Earths systems including processes occurring on land, oceans and in the lower atmosphere. This data can be used to predict global environmental change (NASA, 2019). More in-depth details of the MODIS suite of products can be found in the report conducted by BioTrack, 2019.

The MOD17A3HGF Version 6 MODIS product provides annual information about global Net Primary Production (NPP) at a 500 meter resolution (USGS, 2019). The annual NPP is derived from the MOD17A2H product which derives the sum of 8-day Net Photosynthesis (PSN) throughout the year.

The annual NPP in Catchment T35 A-E fluctuates (Figure 17) from year to year and the general trends can most likely be correlated with average yearly rainfall in the Catchment. However, in Figure 17 we can see clear trends of areas that have high NPP such as forested and plantation areas and areas with much lower NPP such as valley bottom areas in the lower catchment. Grasslands on the whole exhibit lower NPP than the areas dominated by woody vegetation.

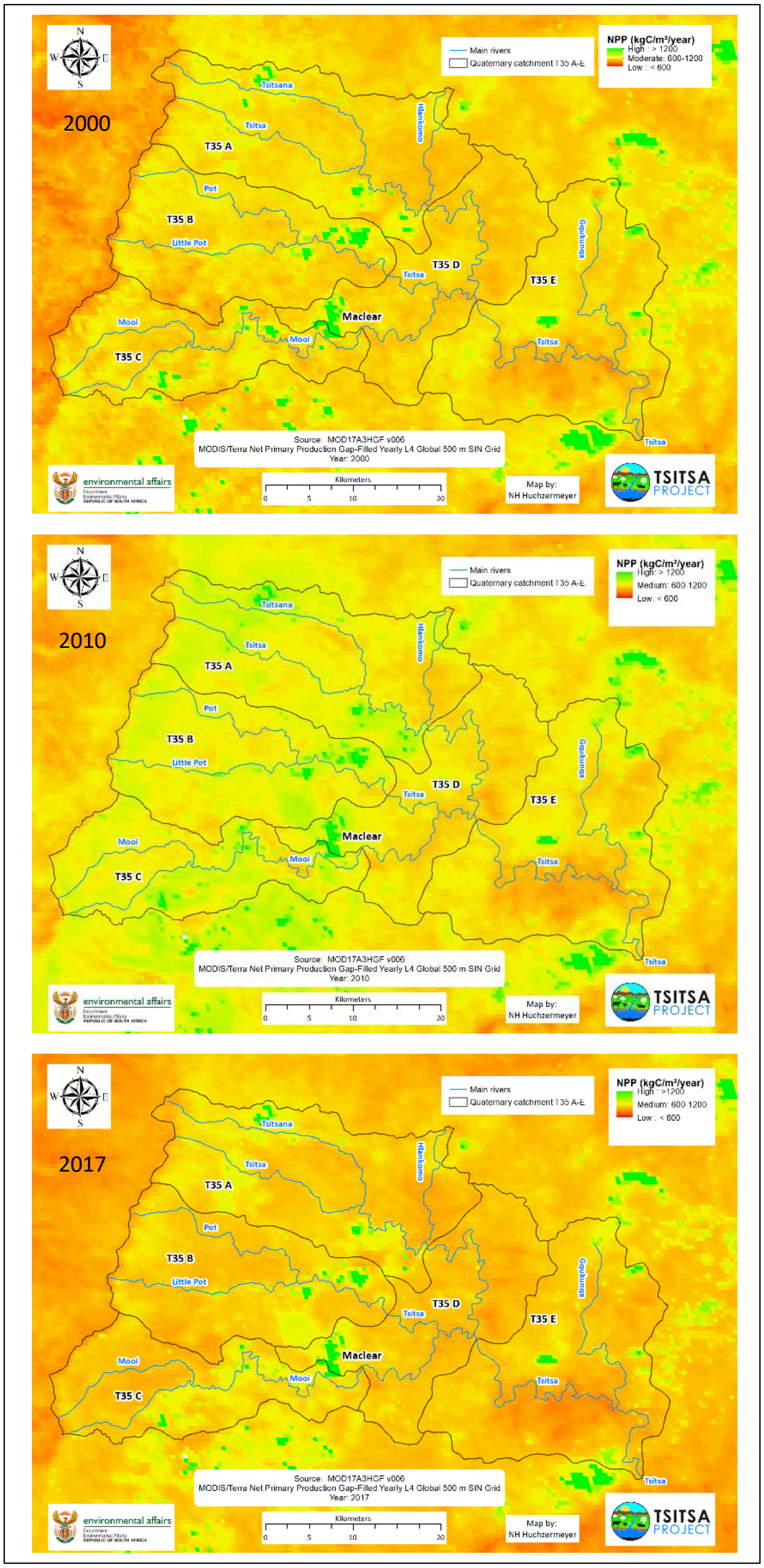


FIGURE 17: YEARLY MEAN NET PRIMARY PRODUCTION (NPP) IN CATCHMENT T35 A-E AND SURROUNDS IN 2000, 2010 & 2017

Trends in rangeland performance and forage production over the past two decades were evaluated at five grassland sites by **Biotrack (2019)** in Catchment T35 A-E. The following details are taken from the Biotrack (2019) report for Catchment T35 A-E. The sites comprised a range of land tenure types, management regimes and condition classes in Catchment T35 A-E. A time series analysis (2000/2002-2019) of Leaf Area Index (LAI), Normalized Difference Vegetation Index (NDVI), and Net Photosynthetic Activity (PsnNet), analogous to net primary production, derived from surface reflectances retrieved by the MODIS satellite sensor.

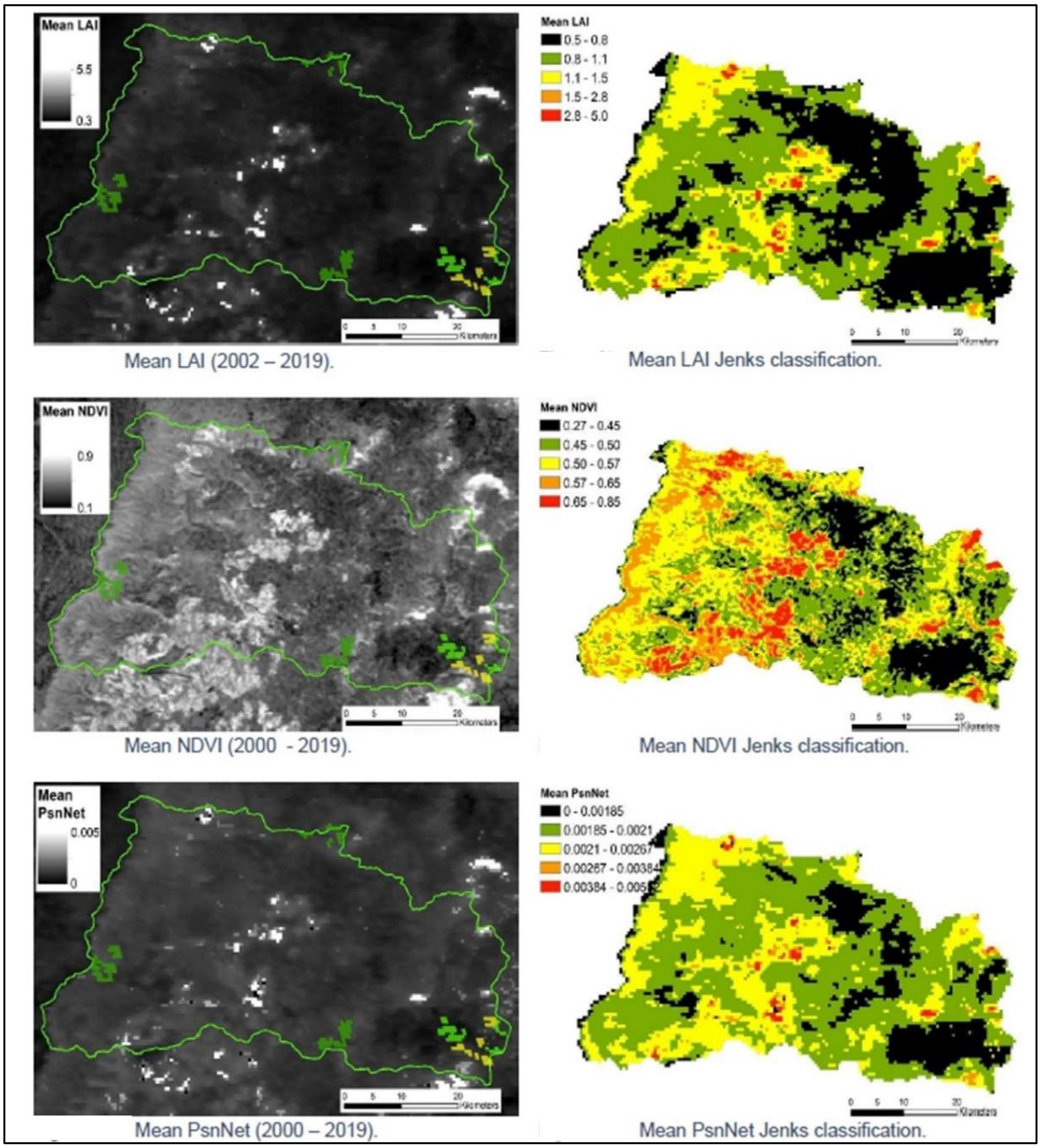


Figure 18: Mean Leaf Area Index (2002-2019), NDVI and PsnNet (2000-2019) for Catchment T35 A-E (Maps by Biotrack, 2019)

The spatial distribution of vegetation productivity classes across the sub-catchments has a clear trend of areas with high values in a north-south direction through the center of the catchment which receives high rainfall and contains commercial plantations. Low values occur predominately in the north-eastern and south-eastern corners of the lower catchment which exhibits large areas of land degradation.

The MODIS data was analysed using the BFAST package in R. BFAST decomposes the time series data to extract trend and seasonal components and residuals, and detects breakpoints that may reflect vegetation responses to climatic shifts or anthropogenic disturbances. Thematic maps of primary productivity are generated for the entire sub-catchment area, and long-term MODIS estimates of forage availability used to calculate grazing capacities at each of the five study sites.

Of the five study sites, productivity is consistently higher in remote, ostensibly relatively intact grasslands in the upper catchment areas, with lowest production values detected in association with abandoned cultivated lands in communal areas; LAI, NDVI, and PsnNet time series generally demonstrate relatively unique responses in upper and lower catchment sites in terms of both trend directions and the timing of breakpoints, with trends typically more stable and with fewer breakpoints in the former; this may reflect lower levels of human disturbance in these systems, possibly a factor of their remoteness and less palatable grazing characteristic of higher elevations. These differences notwithstanding, across all sites and variables, breakpoints generally coincide in 2003/2004, 2007/2008 and 2010/2011, but show very little agreement between variables after these years; with regards to LAI, breakpoints generally correspond between sites again in 2013/2014, NDVI in 2015/2016, and PsnNet in 2017/2018. Time series at nearly all sites demonstrate gradual declines in productivity overall in the last two decades.

Grazing capacities are calculated to be highest in the lower catchment areas despite lower levels of forage production at these sites, since grasses on alkaline soils in floodplains and valley bottoms are more palatable than 'sour' erect perennial robust grasses in the uplands. Grazing capacities vary from 7.2 – 8.8 hectares per large stock unit (Ha/LSU) in lower catchment sites, to 13.9 – 14 Ha/LSU in the upper catchment sites. Significantly, all grazing capacities calculated in this study are considerably lower than the average long-term grazing norms for the grassland biome provided by DAFF, which are 4 – 6 Ha/LSU.

6.3.1. Productivity results from Trends.Earth

Trends.Earth uses bi-weekly products from MODIS and AVHRR to compute annual integrals of NDVI (surrogate to NPP). Land productivity is assessed by combining three measures of change derived from NDVI namely,

1. Trajectory: Rate of change in primary productivity over time (2001-2015).
2. Performance: Measures local productivity relative to similar vegetation types in similar land cover types within the study area
3. State: Detects recent changes in primary productivity compared to an initial/baseline period.

The study area is then classified into 5 classes (improving, stable, stable but stressed, early signs of decline, declining; Figure 19).

Table 10 & Figure 19 show the changes in productivity in Catchment T35 A-E from 2001-2015. To fit in with the SDG indicator, areas are considered as improved if they exhibit improving productivity, stable if they exhibit stable productivity and degraded if they exhibit stressed, moderately declining and declining productivity. Areas of woody vegetation show stable and increasing productivity where as a large proportion of the grasslands are showing a declining productivity. Out of the total land area in Catchment T35 A-E 13% has improved in productivity, 49% of the land area has remained stable and 38% has declined in productivity and can be classified as degraded in terms of productivity.

TABLE 10: SUMMARY OF CHANGE IN PRODUCTIVITY IN CATCHMENT T35 A-E FROM 2001-2015 (SOURCE: TRENDS.EARTH)

	Area (sq km)	Total land area (%)
Total land area	2011.7	100.00
Land area with **improved** productivity	264.4	13.14
Land area with **stable** productivity	986.2	49.02
Land area with **degraded** productivity	761.1	37.83
Land area with **no data**	0	0.00

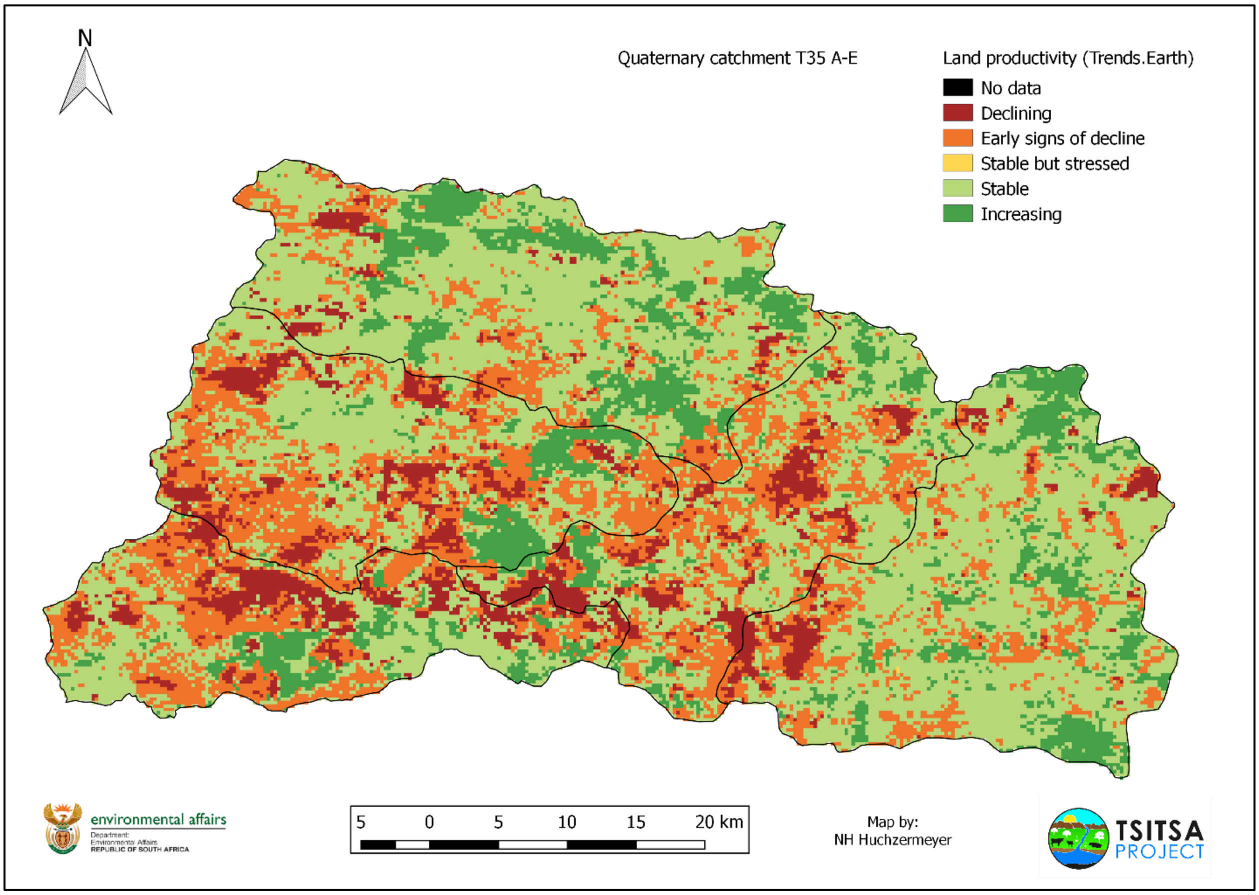


FIGURE 19: PRODUCTIVITY IN CATCHMENT T35 A-E FROM 2001-2015

The area of each class of land productivity found in different land cover classes (described in the next section) can be found in Appendix 1.

6.4. Carbon Stock

Carbon stock as defined by the United Nations (2019) is the quantity of carbon stored in an area which has the capacity to either accumulate or release carbon. Carbon stocks comprise of above and below ground biomass, dead organic matter and soil organic carbon. **Soil Organic Carbon (SOC)** was adopted as the metric for carbon stocks.

The following details of SOC is taken from the Global Soil Partnership (2017) brochure which accompanies the Global Soil Organic Carbon Map. SOC is the carbon remaining in the soil after the partial decomposition of any materials produced by living organisms (Global Soil Partnership, 2017). The natural SOC levels fluctuate depending on the climate, geology, land use and land management in different areas. SOC is a dominant component in Soil Organic Matter (SOM). SOM in turn is critical in the following:

- stabilisation of soil structure,
- retention and release of plant nutrients,
- sustaining water infiltration and storage within the soil,
- ensuring healthy soils for ecosystems and food production.

The loss of SOC indicates a level of soil degradation. The biggest loss of SOC is due to unsustainable land management practices causing bare soils and lack of vegetation. Erosion once initiated acts as pathway for dissolved organic carbon to be leached out of the soils and transported away compounding the soil degradation. By restoring healthy soils, through sustainable land management, in areas where the SOC has been lost it is will not only benefit ecosystems and livelihoods but also help mitigate some of the effects of climate change by reducing the atmospheric CO_2 concentrations.

The global soil carbon map consists of national SOC maps, developed as 1 km soil grids, covering a depth of 0-30 cm. Figure 20 shows the SOC levels in the Tsitsa Catchment and surrounding landscape sourced from the global soil carbon map 2018. The SOC levels are highest in the higher altitude grasslands as well as in the presence of woody vegetation. The eroded areas, particularly in the river valleys where large areas of the land have been cultivated and left bare, exhibit very low levels of SOC.

The SOC levels can be increased by practising sustainable soil management which may include the following:

- sustainable grazing ensuring good grass cover and grass species,
- protection of wetlands,
- in cultivation mulching, planting cover crops, appropriate fertilisation and moderate irrigation.

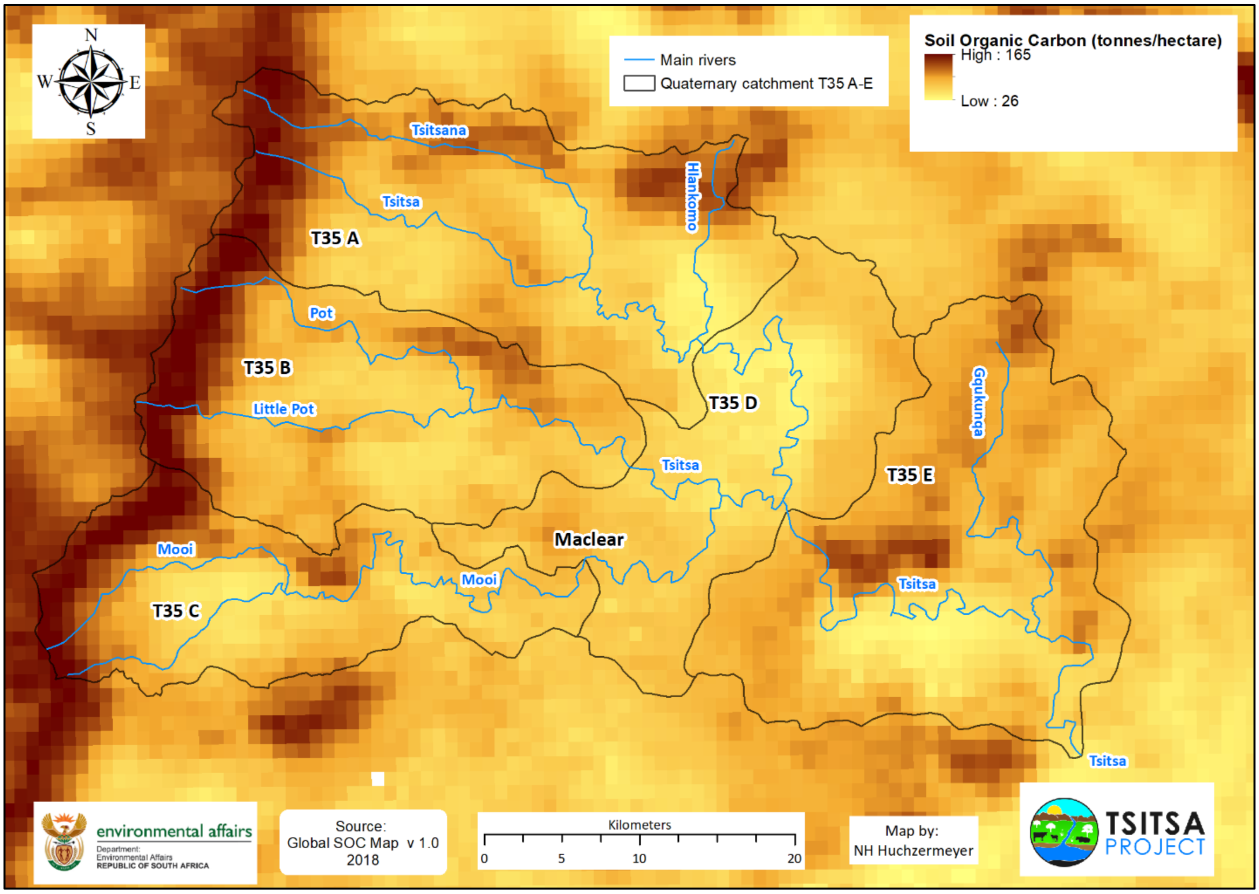


FIGURE 20: SOIL ORGANIC CARBON FOR 2018 IN THE TSITSA CATCHMENT

6.4.1. Soil organic carbon (SOC) results from Trends.Earth

Changes in SOC are difficult to assess due to the variability of soil properties and the lack of time series data on SOC for most regions in the world (Trends.Earth, 2019). Trends.Earth uses a combined land cover/SOC method to address these limitations. This method estimates changes in SOC and identifies potentially degraded areas.

Trends.Earth computes the changes in SOC as follows:

- By default Trends.Earth determines SOC reference values from SoilGrids 250m carbon stocks for the first 30 cm of the soil profiles. However, the global soil organic carbon map (Global Soil Partnership, 2017) is a more recent dataset and was inputted into this step for this analysis. The global soil carbon map consists of national SOC maps, developed as 1 km soil grids, covering a depth of 0-30 cm.
- The land cover classes were reclassified as explained in section 6.2.1. 1990 was used as the start year and 2018 as the end year.
- To estimates the changes in carbon stock recommended carbon conversion coefficients for changes in land use, management and inputs are used. These are recommended for different climatic regions by the IPCC and the UNCCD. However, spatially explicit information on management and carbon inputs is not available for most regions. Therefore only land use conversion coefficients can be applied for estimating changes in carbon stocks (land cover used

as proxy for land use). Trends.Earth use coefficients obtained from the UNCCD. Details can be found on the Trends.Earth website (Trends.Earth, 2019).

- Trends.Earth computes relative difference in SOC between the start and end period. Areas that experience a >10% during the reporting period are defined as degraded and areas that experience an increase of <10% are potentially improved.

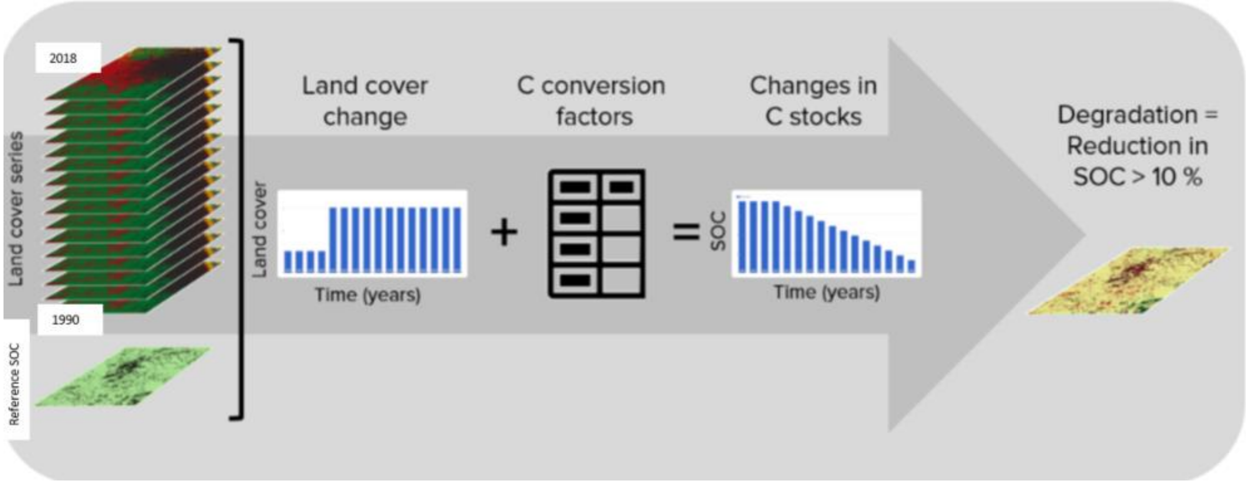


FIGURE 21: COMPUTING STEPS IN ESTIMATING CHANGES IN SOC IN TRENDS.EARTH

Table 11 and Figure 18 show the changes in SOC from 1990-2018 in Catchment T35 A-E. Approximately 6% of the land area has seen an improvement in SOC, 87% has remained stable and 7% has seen a reduction in SOC (degraded).

TABLE 11: SUMMARY OF CHANGES IN SOC FROM 1990-2018

	Area (sq km)	Total land area (%)
Total land area	2011.7	100.00
Land area with **improved** SOC	115.7	5.75
Land area with **stable** SOC	1 753.3	87.15
Land area with **degraded** SOC	130.8	6.5
Land area with **no data**	12	0.59

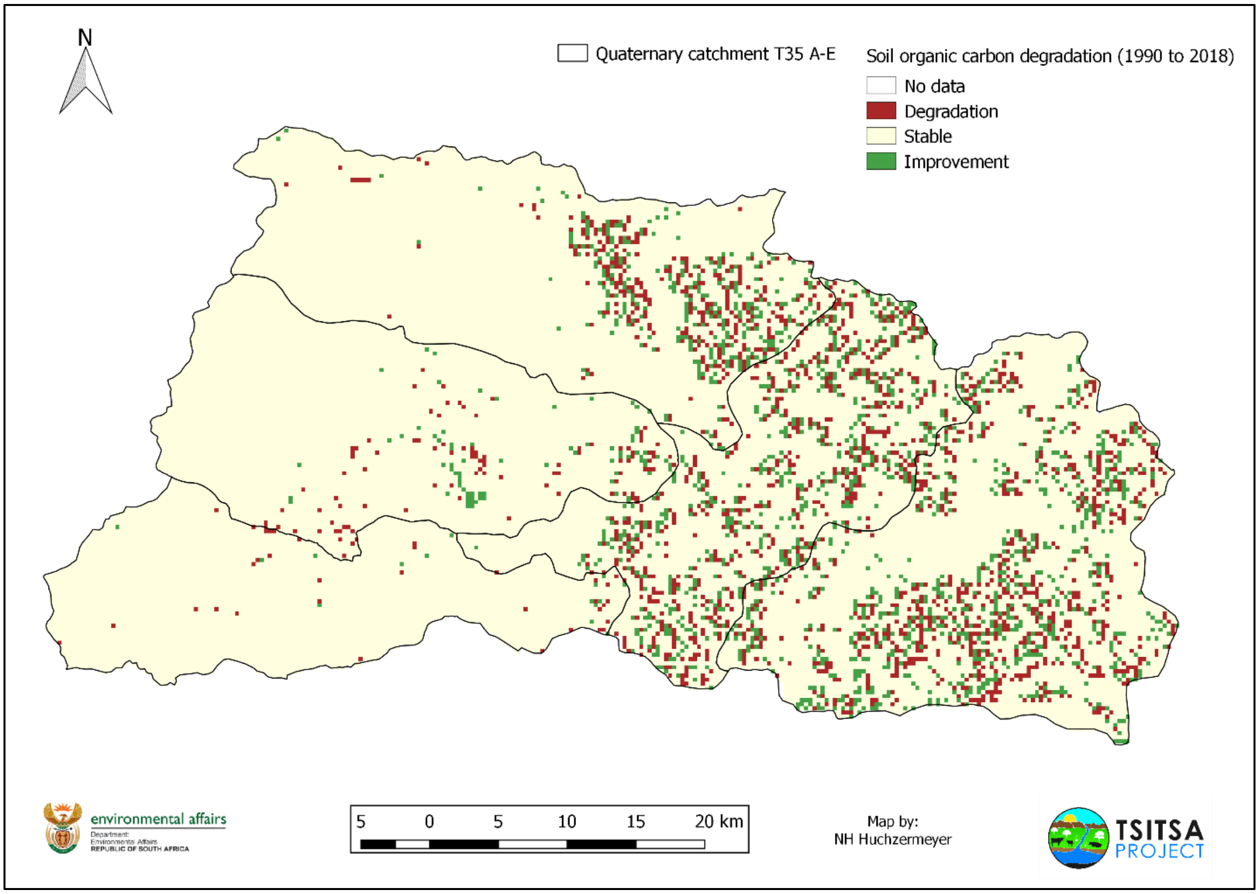


FIGURE 22: POSITIVE AND NEGATIVE CHANGES IN SOC IN CATCHMENT T35 A-E FROM 1990-2019

6.5. Combining sub-indicators for SDG 15.3.1.

The three sub-indicators are integrated following the **one-out all-out** rule (Trend.Earth, 2019; United Nations, 2019). This implies that if an area is defined as degraded in any of the three sub-indicators then that area is considered as being potentially degraded and should be reported as such. Trend.Earth aggregates the three sub-indicators as shown in

Productivity	Land Cover	SOC	SDG 15.3.1
Improvement	Improvement	Improvement	Improvement
Improvement	Improvement	Stable	Improvement
Improvement	Improvement	Degradation	Degradation
Improvement	Stable	Improvement	Improvement
Improvement	Stable	Stable	Improvement
Improvement	Stable	Degradation	Degradation
Improvement	Degradation	Improvement	Degradation
Improvement	Degradation	Stable	Degradation
Improvement	Degradation	Degradation	Degradation
Stable	Improvement	Improvement	Improvement
Stable	Improvement	Stable	Improvement
Stable	Improvement	Degradation	Degradation
Stable	Stable	Improvement	Improvement
Stable	Stable	Stable	Stable
Stable	Stable	Degradation	Degradation
Stable	Degradation	Improvement	Degradation
Stable	Degradation	Stable	Degradation
Stable	Degradation	Degradation	Degradation
Degradation	Improvement	Improvement	Degradation
Degradation	Improvement	Stable	Degradation
Degradation	Improvement	Degradation	Degradation
Degradation	Stable	Improvement	Degradation
Degradation	Stable	Stable	Degradation
Degradation	Stable	Degradation	Degradation
Degradation	Degradation	Improvement	Degradation
Degradation	Degradation	Stable	Degradation
Degradation	Degradation	Degradation	Degradation

FIGURE 23: 'ONE OUT ALL OUT' PROCEDURE FOR INTEGRATING THE THREE SUB-INDICATORS

With only 14% improvement in land, 51% of the land area remaining stable and a staggering 36% degraded, the Tsitsa Catchment paints a sad picture in terms of restoration and meeting the SDG goals (Table 12 & Figure 24). However, the degradation within the catchment is linked closely to the loss of grasslands as well as the low productivity rates in parts of the grasslands. By targeting these two aspects the land in Catchment T35 A-E can be improved drastically.

Many of the areas that have improved are planted forests and alien vegetation (linked to improved land productivity & higher soil organic carbon). However, this improvement is not necessarily a benefit to the ecosystem services within the catchment.

TABLE 12: AGGREGATION OF SDG 15.3.1 SUB-INDICATORS BY TRENDS.EARTH

	Area (sq km)	Total land area (%)
Total land area	2016.5	100.00
Land area **improved**	272.5	13.51
Land area **stable**	1 022.0	50.68
Land area **degraded**	722.1	35.81
Land area with **no data**	0.0	0.00

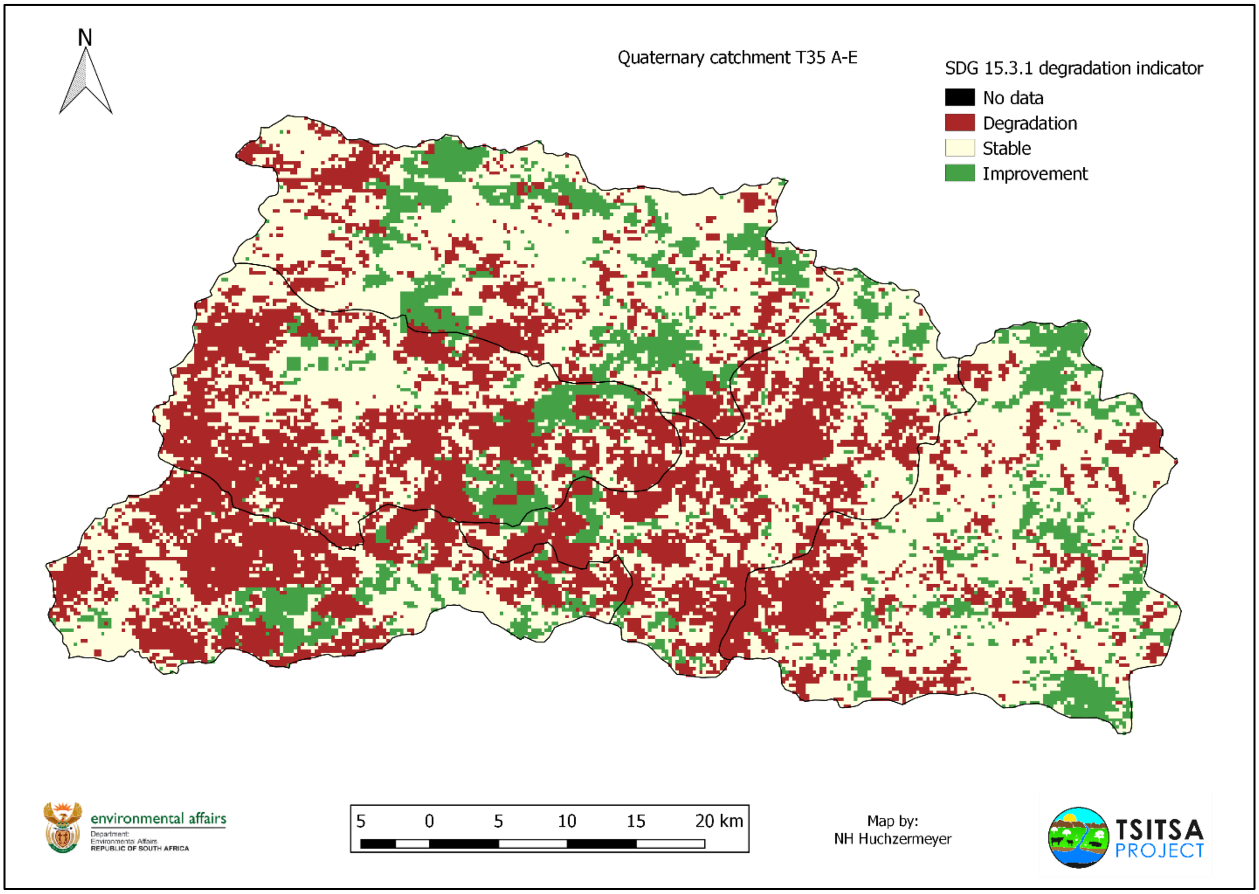


FIGURE 24: LAND AREAS IN CATCHMENT T35 A-E THAT HAVE REMAINED STABLE, ARE DEGRADED OR HAVE IMPROVED ACCORDING TO SDG INDICATOR 15.3.1.

Figure 25 shows the results of Indicator 15.3.1 for the whole of South Africa (this is just a general computation and is not biome/area specific). However, it still puts the degradation that we see in the Tsitsa Catchment in perspective when analysing degradation with this method. There is also a clear trend that the results are closely linked to land productivity (forested or bushy areas are showing an improvement) whereas the grassland areas are generally showing degradation.

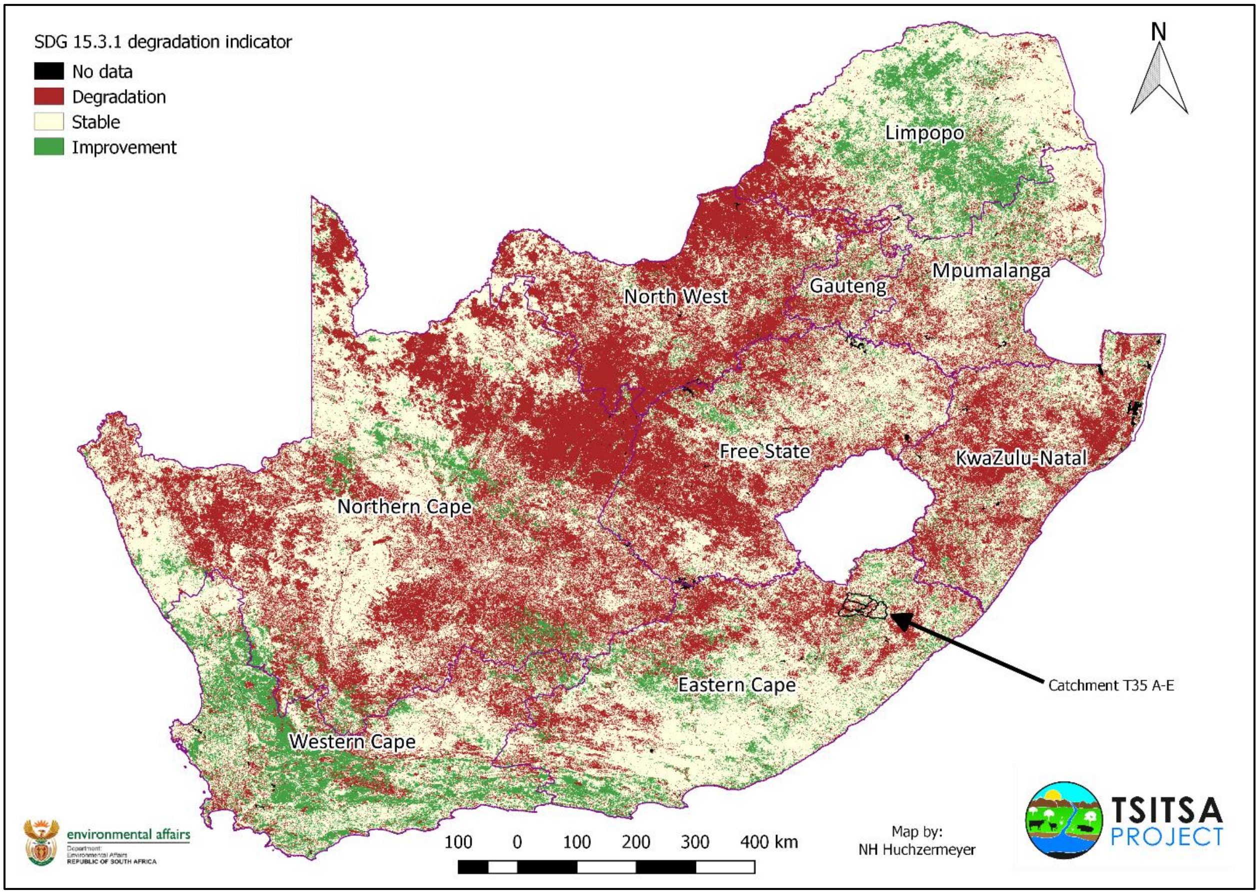


Figure 25: Land area in South Africa that have remained stable, are degraded or have improved according to SDG indicator 15.3.1.

7. CONCLUDING REMARKS

A recent review by Prince (2019) details the challenges that arise when using remote sensing for the Sustainable Development Goal (SDG 15.3.1) productivity indicator. The challenges that are highlighted (Figure 26) include that remotely sensed vegetation data on their own are inadequate to classify or monitor land degradation and the lack of development in understanding the physiological and ecological characteristics of different plant functional groups and how they reflect on remotely sensed vegetation indices. Prince (2019) also points out the need to understand how different ecological processes transform the available NPP to valuable goods and services. Prince (2019) stresses the importance of having baselines and reference conditions that specify the productivity of certain land areas in the absence of anthropogenic causes of land degradation. Therefore, Prince (2019) concludes that the use of vegetation-indices to remotely-sense degradation is not adequate for interpreting the SDG 15.3.1 productivity indicator.

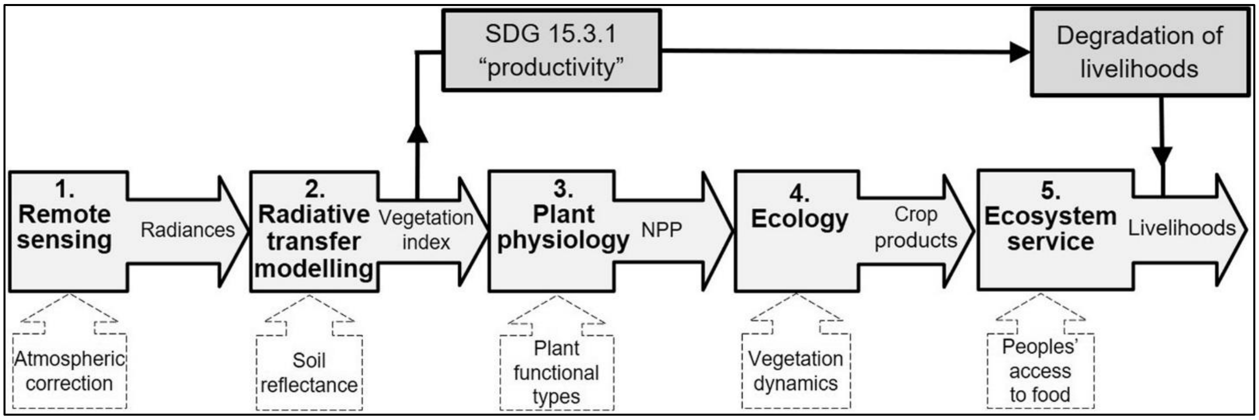


FIGURE 26: FIGURE FROM PRINCE (2019) SHOWING HOW THE SDG 15.3.1 PRODUCTIVITY INDICATOR LEAVES OUT IMPORTANT STEPS WHICH RESULTS IN ERRONEOUS DEGRADATION RESULTS

This could explain the high level of 'degradation' displayed in Catchment T35 A-E (and the rest of SA) when using remote sensing techniques such as Trends.Earth to establish land productivity. It is important to note that these methods are designed for a very course (global) scale and when zoomed into a catchment scale the results are either both variable between different methods (e.g. BioTrack, 2019 & Trends.Earth) and do not accurately reflect was is actually happening on the ground when compared to finer scale data. Therefore, the current work that the Tsitsa Project has done to build baseline data at a catchment and site scale is very important to monitor changes in degradation. It is imperative to continue with the biophysical monitoring on the ground to help supplement the remotely sensed data.

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APPENDIX 1: CHANGES IN LAND PRODUCTIVITY IN DIFFERENT LAND COVER CLASSES

Area of land with improving productivity by type of land cover transition (sq. km)

Land cover type in baseline year	Land cover type in target year: Tree-covered areas	Grasslands	Croplands	Wetlands	Artificial areas	Other lands	Water bodies	*Total:*
Tree-covered areas	28.25	15.23	0.64	0.91	0.48	0.27	0.16	*45.94*
Grasslands	75.80	90.37	5.93	2.72	3.47	2.08	0.27	*180.64*
Croplands	1.33	6.56	10.30	0.37	0.53	0.43	0.16	*19.70*
Wetlands	3.58	4.22	0.64	1.71	0.05	0.11	0.11	*10.42*
Artificial areas	0.53	1.71	0.43	0.00	1.71	0.05	0.00	*4.43*
Other lands	0.53	1.34	0.11	0.05	0.32	0.05	0.00	*2.40*
Water bodies	0.00	0.00	0.05	0.00	0.00	0.00	0.00	*0.05*
Total:	*110.03*	*119.43*	*18.10*	*5.77*	*6.57*	*2.99*	*0.69*	***263.58***

Area of land with stable productivity by type of land cover transition (sq. km)

Land cover type in baseline year	Land cover type in target year: Tree-covered areas	Grasslands	Croplands	Wetlands	Artificial areas	Other lands	Water bodies	*Total:*
Tree-covered areas	23.76	55.35	1.66	1.34	1.07	0.80	0.32	*84.28*
Grasslands	69.04	578.47	32.14	7.85	19.76	10.25	0.75	*718.26*
Croplands	4.43	26.86	51.16	2.14	2.78	0.96	0.75	*89.07*
Wetlands	3.10	12.40	3.53	6.04	0.64	0.27	0.21	*26.18*
Artificial areas	1.50	18.10	2.62	0.53	26.91	1.39	0.05	*51.10*
Other lands	1.07	7.74	1.28	0.00	1.28	0.69	0.00	*12.06*
Water bodies	0.00	0.05	0.16	0.05	0.00	0.00	0.00	*0.27*
Total:	*102.89*	*698.96*	*92.54*	*17.95*	*52.43*	*14.36*	*2.08*	***981.22***

Area of land with stressed productivity by type of land cover transition (sq. km)

Land cover type in baseline year	Land cover type in target year: Tree-covered areas	Grasslands	Croplands	Wetlands	Artificial areas	Other lands	Water bodies	*Total:*
Tree-covered areas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.00*
Grasslands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.00*
Croplands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.00*
Wetlands	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.00*
Artificial areas	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.00*
Other lands	0.00	0.00	0.00	0.00	0.00	0.05	0.00	*0.05*
Water bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.00*
Total:	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.05*	*0.00*	***0.05***

Area of land with moderate decline for productivity by type of land cover transition (sq. km)								
	Land cover type in target year							
Land cover type in baseline year	Tree-covered areas	Grasslands	Croplands	Wetlands	Artificial areas	Other lands	Water bodies	*Total:*
Tree-covered areas	13.99	35.40	1.28	0.59	0.05	0.48	0.11	*51.90*
Grasslands	37.64	338.28	18.42	3.95	4.70	3.26	1.01	*407.25*
Croplands	2.35	13.88	22.64	1.07	0.91	0.43	0.16	*41.43*
Wetlands	3.15	7.85	1.55	3.74	0.05	0.11	0.11	*16.56*
Artificial areas	0.43	5.66	0.59	0.00	6.19	0.32	0.00	*13.19*
Other lands	0.48	2.13	0.48	0.00	0.11	0.05	0.21	*3.47*
Water bodies	0.05	0.00	0.00	0.00	0.00	0.00	0.00	*0.05*
Total:	*58.09*	*403.21*	*44.96*	*9.35*	*12.01*	*4.64*	*1.60*	***533.86***

Area of land with declining productivity by type of land cover transition (sq. km)								
	Land cover type in target year							
Land cover type in baseline year	Tree-covered areas	Grasslands	Croplands	Wetlands	Artificial areas	Other lands	Water bodies	*Total:*
Tree-covered areas	15.43	23.81	1.12	0.64	0.11	0.16	0.11	*41.37*
Grasslands	19.06	115.72	6.73	2.78	0.53	0.48	0.21	*145.50*
Croplands	1.17	6.57	19.17	0.53	0.16	0.27	0.05	*27.93*
Wetlands	0.59	4.22	1.34	2.14	0.21	0.00	0.00	*8.49*
Artificial areas	0.11	0.43	0.05	0.00	1.34	0.05	0.00	*1.98*
Other lands	0.05	0.48	0.00	0.00	0.00	0.00	0.00	*0.53*
Water bodies	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.00*
Total:	*36.40*	*151.22*	*28.41*	*6.09*	*2.35*	*0.96*	*0.37*	***225.81***