EARTH OBSERVATION AND THE IN-SITU-BASED ASSESSMENT OF THE IMPACTS OF LAND USE AND LAND COVER CHANGES ON WATER QUALITY AND QUANTITY IN KEY WATER RESOURCES OF LIMPOPO AND THE EASTERN CAPE, SOUTH AFRICA

Report to the

WATER RESEARCH COMMISSION

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EXECUTIVE SUMMARY

Background and Rationale

The human footprint on the environment herein referred to as Land Use and Land Cover Changes (LULCC) is among the principal drivers triggering land, and water quality and quantity degradation. Specifically, anthropogenic activities, such as agriculture, forestry, industrialisation, mining and urbanisation often lead to LULC changes, which increases effluent discharge into surface water resources. These activities also tend to increase runoff, especially from paved surfaces in urban areas and poorly managed croplands, leading to increased transport of pollutants into open water bodies affecting water quality and quantity. The quality of water in major rivers, particularly in the selected catchments in Limpopo and some parts of the Eastern Cape provinces, show high degrees of pollution, particularly from both point and non-point sources. In addition, LULC changes contribute to land degradation, which results in the loss of soil organic matter as carbon dioxide and provides a potentially large climate change feedback and a significant source of uncertainty for climate estimates. Limited efforts have been made to investigate the impacts of the inherent LULCC on water quality and quantity in the Limpopo and the Eastern Cape provinces, primarily due to the largely rural nature of the two provinces. In response to the aforementioned challenges, the Water Research Commission (WRC) contracted the Risk and Vulnerability Science Centre (RVSC) at the University of Limpopo, in collaboration with its associated centres and collaborators at the University of Fort Hare, Walter Sisulu University and the University of the Western Cape, to apply earth observation techniques and in-situ-based assessments to determine the impacts of land use and land cover changes on water quality and quantity in key water resources from three selected catchments.

Objectives

The specific objectives of the project were to**:**

1) Apply remote sensing techniques to map LULC changes and surface water bodies in the Letaba River Catchment in Limpopo, Keiskamma, and Mthatha River Catchments in the Eastern Cape Provinces over the past 19 years

2) Assess the effect of LULC changes on water quality and quantity

3) Identify the sources of the pollutants in these three river catchments

4) Determine the effect of LULC changes on soil organic carbon stocks, soil CO_2 emission, and hydraulic and other physical soil properties
5) Assess the socio-economic drivers of LULC changes along with the mitigation and adaptation strategies
6) Build the capacity of postgraduate students in the research field of land use and water pollution.

Methodology, findings and conclusions

Using the appropriate approaches and methodologies, the specified objectives were realised as deliverables. In this section, the summarised methodologies employed, outcomes, and conclusions of the objectives are described. Recommendations are also provided to guide future work in managing water pollution.

Objective 1: Maps on Land Use Land Cover Changes

To accomplish this objective, multi-source satellite datasets comprising the Landsat Enhanced Thematic Mapper (ETM+); and Landsat Operational Land Imager (OLI) were used to map long-term changes in land cover in the Letaba, Keiskamma, and Mthatha River Catchments for the period between 1994 and 2020. However, cloud-free images were unavailable in some catchments, resulting in noticeable discrepancies in image acquisition dates. Spatial distributed locational points, collected at sub-meter accuracy using a hand-held Global Positioning System (GPS) were used for the training of the classification model and validation. Satellite image classification was done, using the commonly used maximum likelihood classification algorithm. The three river catchments were classified into ten major land use/cover classes viz. cultivated lands, built-up, plantations, water bodies, bare surfaces, grasslands, natural forests, shrublands, wetlands and burn scars. Results of the study demonstrated that LULC changes have occurred in the upper, middle, and lower parts of the three catchment areas. For instance, the results from the Keiskamma catchment point to marginal long-term changes in most land cover types, with an increase of not more than 3%, except for bare land, which exhibited a decline of 3.32% throughout the monitoring period. During the 19-year period, the built-up regions experienced the highest increase of 2.84%. Apart from bare land, which increased by 5.47 percent, the data for the Mthatha catchment indicated a marginal and long-term decrease of 3 percent for the majority of cover categories. In contrast, in the Letaba basin, shrublands and bare surfaces declined by 7.72%

and 19.47%, respectively. Strikingly, due to the increase in human population, the built-up areas have increased by 12.18% in Letaba Catchment during the 26-year study period. Although there has been a minor shift in the different land cover and land use types mapped across the three catchments, the study concludes that there have been no significant changes ($\sigma = 0.05$) over the 19 and 26 years studied. Despite this finding, it is necessary to regularly monitor and assess the effects of LULC changes on the quantity and quality within each of the three catchments in order to conserve surface water resources and identify problems before they become unmanageable. We also recommend the development of a regional framework and guidelines for sustainable land management including all sectors of land use which extends to cropping, forestry and urbanization in the three catchment areas. It is also important to note that there is a need to review and streamline policies that encourage noncompliance to regulations of managing land use activities such as plantations (i.e. citrus and eucalyptus). For example, all policies that may encourage or result in soil erosion such as riverbanks cultivation within the three catchments must be amended. Powers should be invested in local authorities to take part in protecting the environment and/or in planting trees, and the government should be able to provide seedlings for the operation.

Objective 2: LULC changes effect on water quality and quantity

The impact of changes in land use and land cover within the three catchments was assessed through spatially explicit earth observation techniques and in-situ techniques in three separate sections/reaches (upper, middle, and lower) of the main rivers. During each survey, water temperature (T) (°C), pH, dissolved oxygen (DO) (mg/L), electric conductivity (EC; µS/cm), total dissolved solids (TDS;) and salinity (SAL) (ppt) were measured in-situ at each site using a handheld YSI Model 554 Data logger multiprobe. Water quality parameters across the three selected river catchments were modelled using a medium resolution (10 m) dataset including Sentinel 2 MSI satellite images which corresponded to the month of sampling.

The results indicate a strong correlation (-0,50<r>0,79) between the bands mainly in the visible and red-edge region of the electromagnetic spectrum (2,3,4,5) and in-situ water quality parameters such as DO, EC, TDS, SAL and PH. Water indices such as the Normalised Difference Turbidity Index (NDTI), Land Surface Water Index (LSWI), and Automated Water Extraction Index (AWEIsh) portrayed strong correlations (-0,50<r> 0,89) with water quality parameters. However, electrical conductivity and total dissolved solids yielded the best strong regression models using Sentinel 2 band 7, band 8, NDTI, and

AWEIsh. Dissolved oxygen, salinity, temperature and pH models on the other hand produced less striking results with coefficient determination (R2) lower than 0,5 (dissolved oxygen and pH) and as high or better than > 0. 55 (salinity and temperature).

In terms of water quantity, the total area covered by water in the Letaba watershed expanded from 717 ha in 1994 to 1889 ha in 2020, resulting in an increase from 0.08% to 0.2% of the entire catchment area, whereas the quantity of water in the Keiskamma catchment fluctuated from 1994 to 2020. The results also demonstrated that, in the Mthatha catchment, the area occupied by water decreased from 14152 ha in 1994 to 4758 ha in 2020, which represents a -3.65% change in the overall composition of water bodies in response to LULC change.

In conclusion, our investigation confirmed the contamination (eutrophic and organic matter) status of the three catchments for the time period studied. Thus, local authorities, regional agencies, and regional institutions must work collaboratively to carry out meticulous land management plans to minimise further deterioration of the water quality in the three catchments. The findings of the study also confirmed the dependability of earth observation data for water quantity mapping in the three catchments. However, we recommend that machine learning algorithms and data cubes be used in future studies to manage massive geospatial and earth observation datasets. This will facilitate the analysis of remote sensing imagery at scale.

Objective 3: Sources of the pollutants in the selected three river catchments

Water quality can be impacted by both natural and anthropogenic factors. It is also known that land use has a substantial effect on the parameters of water quality. Under this objective, the aim was to determine the effects of different land-use types on the water quality of the three river catchments. The field studies were carried out in 2021 from the upper, middle, and lower reaches of the rivers to assess nutrient profiles using an inductive coupled plasma optical emission spectrometry (ICP-OES). There were significant differences among the rivers in terms of turbidity, nitrate, ortho-phosphate, and ammonia, with the Letaba River having the highest turbidity. In the Mthatha River, significant concentrations of nitrate, orthophosphate, and ammonia were recorded. Nitrate concentrations in the Mthatha River exceeded the WHO-recommended guideline threshold. The concentration of Mn also exceeded SANS, EU and USEPA water quality guidelines for drinking water of the three rivers. Regarding the concentration of lead, it was found to be higher in lower reaches than in the other sections of the rivers. This study recommended that continuous monitoring of nutrient ions and trace metals is necessary, especially in areas with high anthropogenic activities to save these rivers from further degradation.

The use of Pb isotopes to identify sources of heavy metal contamination in the three catchments revealed that the suspected sources in the Mthatha and Letaba catchments might not have been the origin of the pollutants while in Keiskamma the results suggested that the suspected sources might actually be the actual sources of the pollutants. The results of the current study were therefore not conclusive as not all possible sources were sampled therefore additional research to establish the contribution of the various sources is required.

Objective 4: LULC changes on soil organic carbon stocks, soil CO_2 emission, hydraulic and other physical soil properties

Carbon dioxide (CO_2) is the most important greenhouse gas accounting for 60% of the total greenhouse effect and its continuous release from agricultural systems is contributing to global warming. The main objective of this study was to determine the impact of land use and land cover changes on the soil organic carbon stocks, soil CO_2 emission, and hydraulic and other physical soil properties. To achieve the objective, soil CO_2 emission rates were measured every two weeks for twelve months in the Letaba catchment and some in the Keiskamma catchment. Nine land use systems were studied in the Letaba catchment and three in the Keiskamma catchment.

Higher levels of phosphorus were observed in fertilised orchards compared to natural systems, as shown by the study's findings. The amount of soil carbon stocks stored in the forest (thicket) (1.19 kg/m^2) was more than 5 times higher than the amount stored in some of the land use systems such as the bush and citrus orchards (0.23 kg/m^2). This is attributed to a relatively higher litter fall and reduced soil temperatures under the forest. Soil CO_2 emission rates also varied with both season and land use systems in the Letaba Catchment, being higher in the autumn and summer seasons compared to the spring and winter seasons. In the Keiskamma catchment, soil CO_2 emission varied with the land use type and the location. It was observed that on average grasslands released more soil CO_2 compared to croplands and grazing lands. In conclusion, the findings of the study show that the amount of CO_2 released into the atmosphere varied with land use type and that season plays a significant role in the emission rates due to the influence of soil moisture and temperature.

For a comprehensive understanding of the temporal fluctuation of soil CO_2 emission in the various land use systems, it is recommended to measure soil CO_2 emission rates more frequently. Other components, such as microbial decomposer populations and aggregate-associated carbon, must be examined to fully comprehend the primary drivers of soil CO_2 emissions in these various land-use regimes. Finally, it is advised that soil carbon stocks be estimated at a better geographic resolution and to a greater depth in the soil profile in order to fully document the quantity of soil carbon contained in the soils.

Objective 5: Socio-economic drivers of LULC changes along with the mitigation and adaptation strategies.

Land use and land cover changes (LULC) are happening worldwide causing mixed ecosystem impacts and notable disruptions to both livelihoods and natural ecosystems. Understanding land use and land cover changes is critical for environmental management and climate change policy. A desktop study, cross-sectional survey and a triangulation analysis integrating satellite observations and perception survey to establish convergence, complementarity, and dissonance of results on LULC and perceived changes in the Letaba, Keiskamma, and Mthatha catchments using multiple methodologies were undertaken to understand the underlying processes and key socioeconomic factors deriving these processes.

In terms of socioeconomic characteristics, female-headed households were prominent in the Mthatha catchment and Letaba catchments account for approximately 60% of the sampled households. Approximately 100% of the sampled households in the Letaba catchment indicated that land use was changing, with 94% and 63% in Mthatha, and Keiskamma catchments respectively affirming this. More than 50% of the respondents indicated that changing land use has been happening for more than 10 years with a significant increase in the built-up area being reported from the sampled households across the three catchments as inferred from satellite images. Population growth and urbanisation featured as prominently in literature as drivers of LULC in the three catchments. There was significant convergence of respondents' perceptions about the most important drivers of LULC across the three catchments. Demand for new residential areas, farm abandonment, population growth, poverty, lack of financial resources, and climate change emerged as the most important drivers of land use change while land use policies, law enforcement, and lack of awareness were ranked as least important. Respondents across the three catchments concur that education and awareness on land use and enforcement of rules against the harvesting of resources and improper land allocation are key to ameliorating the land use change problem.

Objective 6: Capacity building of postgraduate students

Building the capacity of postgraduate students and academic staff is important in developing new and upcoming researchers and can contribute to national developmental goals. Strong postgraduate participation in the LULC research in the three catchments has the potential to strengthen the academic, research and community engagement programmes of participating universities through a suite of integrated, multi-disciplinary research approaches, which will ultimately lead to significant societal impacts and rural community benefit. In this LULC research project, two Doctoral students and four MSc students were supported. Two MSc students successfully completed their programme and the remaining students are all scheduled to complete in the 2023 academic year. The delay in timely completion was primarily due to the challenges caused by the COVID-19 pandemic restrictions.

Concluding remarks

The analysis of the research revealed that LULC changes have happened to variable degrees in the various sections of the three catchment areas, with the urbanised regions experiencing the greatest increase. Regarding water quality, it can be established that the water in the three catchments has been polluted through organic waste matter and eutrophication.

The significant sources of pollution of the river catchments were turbidity, nitrate, ortho-phosphate and ammonia, nitrate with the highest turbidity recorded in the Letaba River. The level of nitrate, and manganese recorded in the Mthatha River exceeded the WHO-recommended guideline value whereas that of manganese exceeded SANS, EU and USEPA water quality guidelines for drinking water of the three rivers. In all three catchments, the concentration of lead was found to be highest in the lower portions of the rivers.

Regarding stored CO_2 as a potential source of greenhouse gas emissions, the amount of soil carbon stocks stored in the forest (thicket) was more than five times greater than the amount stored in other land use systems, such as the bush and citrus orchards, and this is primarily due to the high litre fall in the forest ecosystem. The results also indicate that the amount of CO_2 released into the atmosphere varies with land use type and that soil moisture and temperature play a key role in determining seasonal emission rates.

Respondents across the three catchments concur that education and awareness on land use and enforcement of rules against the harvesting of resources and improper land allocation are key to ameliorating the land use change problem.

All of the households surveyed in the catchments indicated that land use has changed during the past few years. The respondents indicated an increase in built-up areas throughout all three catchments, which was supported by satellite images. Demand for additional residential areas, farm abandonment, population growth, poverty, a lack of financial resources, and climate change appeared to be the most important drivers of land use change, while agricultural abandonment, poverty, and a lack of financial resources appeared to be the least important. Population growth and urbanization were cited in the literature as primary drivers of LULC in the three catchments. The least important were land use policies, legal enforcement, and a lack of awareness. Respondents from all three catchments concur that education and awareness on land use, as well as the implementation of legislation limiting resource extraction and erroneous land allocation, are necessary to resolve the land use change problem.

In this LULC research project, two Doctoral students and four MSc students were supported. Two MSc students successfully completed their programme and the remaining students are all scheduled to complete in the 2023 academic year.

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Chapter 1: Land Use and Land Cover Change characterization in three catchments in South Africa

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1.1 Abstract

Land use and land cover changes have significant environmental consequences at local, regional, and global scales. These changes have intense implications at the regional and global scales for global loss of biodiversity, distress in hydrological cycles, increase in soil erosion, and sediment loads. Consequently, knowledge about LUCC is critical to the development of policies and action plans necessary for changing current LUCC trends in the area as it has been observed in other places. Multi-date satellite datasets comprising the Landsat Enhanced Thematic Mapper (ETM+); and Landsat Operational Land Imager (OLI) were used to map long-term changes in land cover from three selected catchments namely; the Letaba, Keiskamma, and Mthatha River Catchments. Land cover changes were mapped for the period between 1994 and 2020. However, cloud-free photos were unavailable for some catchments, resulting in noticeable discrepancies in image acquisition dates. Spatial distributed locational points, collected at sub-meter accuracy using a hand-held Global Positioning System (GPS) were used for the training of the classification model and validation. Satellite image classification was done, using the commonly used maximum likelihood classification algorithm in the ArcGIS environment. The three river catchments were classified into ten major land use/cover classes viz. Cultivated lands, Built-up, Plantations, Water bodies, Bare surfaces, Grasslands, Natural forests, Shrublands, Wetlands and Burn scars. Results of the study demonstrated that LULC changes have occurred in the upper, middle, and lower parts of the three catchment areas. For instance, the results from the Keiskamma catchment point to marginal long-term changes in most land cover types, with an increase of not more than 3%, except for bare land, which exhibited a decline of 3.32% throughout the monitoring period. During the 19 years, the built-up regions experienced the highest increase of 2.84%. Except for bare land, which grew by 5.47 percent, the data for the Mthatha catchment indicated a marginal and long-term reduction of 3 percent for the majority of cover categories. In contrast, in the Letaba basin, shrublands and bare surfaces declined by 7.72% and 19.47%, respectively. Strikingly, due to the increase in human population, the built-up areas have increased by 12.18% in Letaba Catchment during the 26 years study period. Although there has been a minor shift in the different land cover and land use types mapped across the three catchments, the study

concludes that there have been no significant changes (σ = 0.05) over the 19 and 26 years studied. Despite this finding, it is necessary to regularly monitor and assess the effects of LULC changes on the quantity and quality of water within each of the three catchments to conserve surface water resources and identify problems before they become unmanageable. The results of this study, thus, have the potential to contribute to a more sustainable use of water resources in the three river catchments of the Limpopo and Eastern Cape South African provinces of South Africa, for the benefit of future generations.

1.2 Introduction

Land use/land cover (LULC) changes are among the principal drivers triggering land, and water quality and quantity degradation (Pan and Choi, 2019). On the contrary, natural causes and anthropogenic activities are the major drivers of LULC dynamics (Munthali et al., 2019), with the latter overriding the former. Anthropogenic activities, such as forestry, agriculture, mining, industrialisation and urbanisation often lead to land-use changes, which increases effluent discharge into water bodies. These activities also tend to increase runoff, especially from paved surfaces in urban areas and poorly managed croplands, leading to increased transport of pollutants into surface water bodies affecting water quality.

Several studies have been conducted around the world on the effects of LULC changes on ecosystem services. For example, a study in Botswana showed that human activities and seasonal flooding resulted in temporal and spatial fluctuations in the water quality of the Thamalakane-Boteti River that drains from the Okavango Delta (Tubatsi et al., 2014; Masamba and Mazvimavi, 2008). In Malawi's Dedza area, substantial declines in forestland, agricultural land, wetlands, and water were reported due to firewood collection, charcoal production, population growth, and poverty (Munthali et al., 2019) while in Australia, Hajkowicz (2002) reported deterioration in the quality of surface water resources due to land management practices. Here in South Africa, in the North West province, a study showed a significant decrease in the quantity and quality of water in ephemeral ponds due to land use activities such as grazing, mining, crop farming, and built-up areas (Asare et al., 2018).

In all these studies, there is no doubt that LULC changes can have detrimental effects on land degradation but it is clear that the activities responsible for land degradation are unique to each environment or catchment. The quality of water in major rivers, particularly in the catchment areas of Limpopo and in some parts of the Eastern Cape provinces, shows high degrees of pollution, from both point and non-point sources of pollution. Point source pollution could be from sewage effluent, industrial effluent, backyard industry discharges, and mining activities, while runoff from urban and cultivated lands could be non-point pollution sources. A closer examination of all causes of pollution reveals the danger and severity of damage to South Africa's river courses. The inflow of high nutrient levels particularly nitrates into rivers, for instance, has contributed to the eutrophication of water bodies. Eutrophication is detrimental to fish and human health. The eutrophication may be caused by sewage effluent or runoff from intensively fertilised farming systems. For effective management of surface water eutrophication, it is necessary to identify the source of nitrates.

The Limpopo and Eastern Cape provinces are primarily rural. As a result, less work has been conducted to evaluate the effects of LULC changes on water quantity and quality. There is limited evidence relating changes in water quality and LULC. There are a few point-based water quality data sources, including that of Moyo and Rapatsa (2019). However, point-based assessments are inadequate in providing information on the spatial variation of LULC changes and water quality at the district level. Remote sensing techniques offer attentively synoptic, repetitive, consistent, cost-effective and comprehensive spatiotemporal views. In addition, most studies characterise water quality without tracing the actual sources of the pollutants. This presents management problems, particularly in areas where there are several sources of pollutants.

Land use and land cover changes are key components of strategies used in managing natural resources and monitoring environmental changes (Prasad and Sreenivasulu, 2014), which can be detected at a temporal scale using remote sensing (Fatemi and Narangifard, 2019). However, in some instances, it may be extremely difficult to obtain multi-date data at the same time of the year, particularly in regions where cloud cover is common (Mas, 1999). Change detection can capture the spatial changes induced by anthropogenic activities from multi-temporal satellite images (Paria and Bhatt, 2012) by finding the changes in images of the same location taken at different times. Change detection is of great importance due to its application in numerous fields (Asokan and Anitha, 2019). This type of data, particularly on the present LULC patterns, spatial distribution, and their changes, is a prerequisite for the formulation of policies and strategies for the development of any plan. Therefore, in this study, LULC changes in the Letaba catchment in Limpopo, Mthatha, and Keiskamma catchments in the Eastern Cape were characterised, using remotely sensed data. This work contributes new knowledge on LULC changes, particularly catchments undergoing rapid developments which is typical of many developing countries and provides spatial explicit information for policymakers and land use planners catchment scale.

1.3 Study area description

1.3.1 Letaba River Catchment

The Letaba River catchment is located between longitudes 30°0′ and 31°40′ East and latitudes 23°30′ and 24°0′ South, in the Mopani District of Limpopo Province, South Africa (Figure 1.1). The Letaba River catchment has a surface area of 67,000 km^2. The Letaba River flows eastwards across the Kruger National Park (KNP), where it joins the Olifants River a short distance upstream of the Mozambique border. The river catchment basin comprised six large dams from upstream to downstream such as Ebenezer Dam, Tzaneen Dam, Modjadji Dam (in the Molototsi River), Hudson Ntsanwisi Dam (in the Nsama River), Middle Letaba Dam (in the Middle Letaba River) and Engelhard Dam. These dams are the major sources of water supply to the towns of Tzaneen, Polokwane Phalaborwa, and villages scattered around the catchment and to agricultural and mining water users. Some of the major tributaries on the left include; the Nharhweni River, Ngwenyeni River, Klein Letaba River, Molototsi River, and Nsama River. Whereas, on the right lies river tributaries such as the Groot Letaba River, Nwanedzi River, and Makhadzi River.

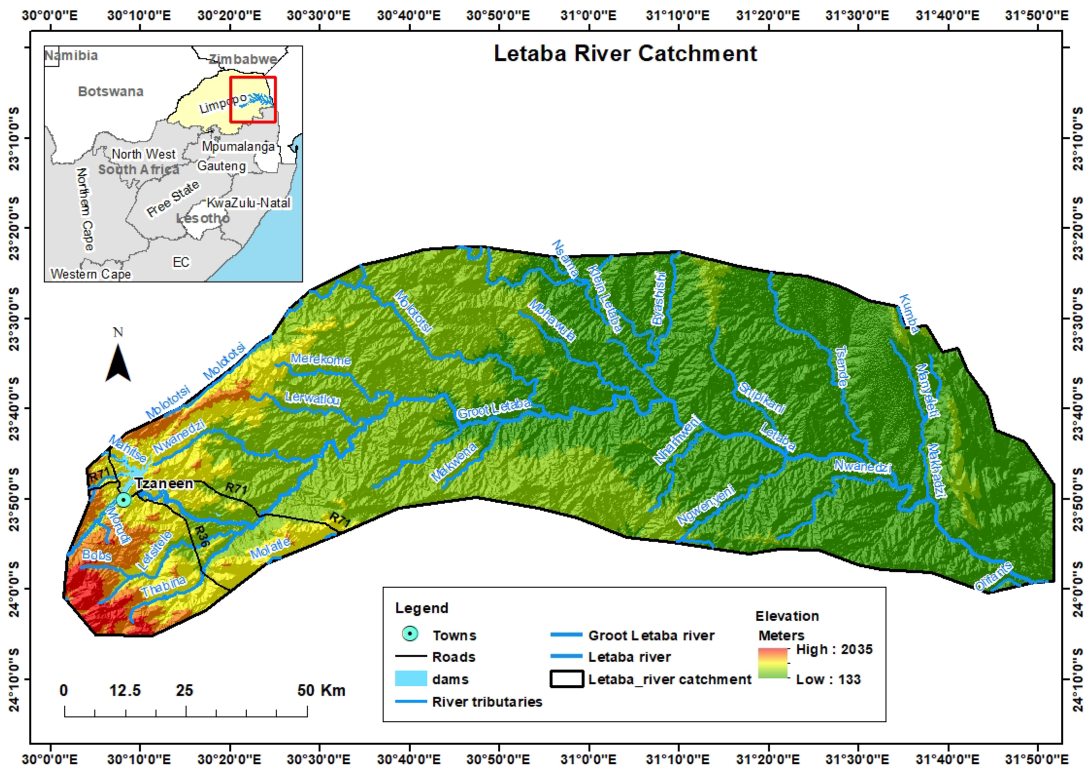

Figure 1.1: Location map of the Letaba River catchment.

The Letaba River changed from a perennial to a non-perennial river in the 1950s, primarily due to the construction of storage dams for domestic and irrigation purposes (Querner et al., 2016). The mean annual runoff (MAR) of the Letaba catchment is 574 mln m^3 (range from 100 to 2 700 mln m^3) (DWAF 2003). Variation in terms of topography (altitude and relief) from east to west around the Letaba River gives rise to different climatic characteristics. For instance, rainfall around the mountainous region of the Letaba River has a yearly average of approximately 2000 mm, while the Lowveld region on the eastern side has a yearly average of 400 mm (State of Rivers Report, 2001). The area is characterised by summer rainfall and normally evaporation rates steadily increase from the west (1400 mm/a) to the east (1900 mm/a) (State of Rivers Report, 2001). The average annual temperature ranges from 21°C in the upper catchments to 25°C in the Lowveld (State of Rivers Report, 2001). Frost rarely occurs. The highest peaks have an elevation of more than 2 000 m, whereas the lowest point has an elevation of 133 m above mean sea level.

1.3.2 Keiskamma River Catchment

The Keiskamma is one of the largest catchments in the semi-arid region of the Eastern Cape Province of South Africa, covering an area of 2 745 km² which forms approximately 35% of the former Ciskei region (Hill, 1991) (Figure 1.2). The Keiskamma river is the main river in the catchment with headwaters situated in the Amatole Mountains above Keiskammahoek town and flows eastwards for 263 km and drains into the Indian Ocean at the resort town of Hamburg (33°17´S 27°29´E). The main tributaries of the Keiskamma River are Tyume, Chalumna and Gulu, with the Tyume headwaters in Hogsback (DWAF, 2004).

Climatic variations in the catchment are highly associated with elevation and proximity to the sea. The escarpment zone, which comprises mountain forests and pine plantations receive annual rainfall amounts of about 1 900 mm while the semi-arid coastal plateau receives 400-600 mm, with most of the rainfall received in summer (Mhangara, 2011). The mean annual rainfall is spatially distributed according to the topographic zonation of the catchment.

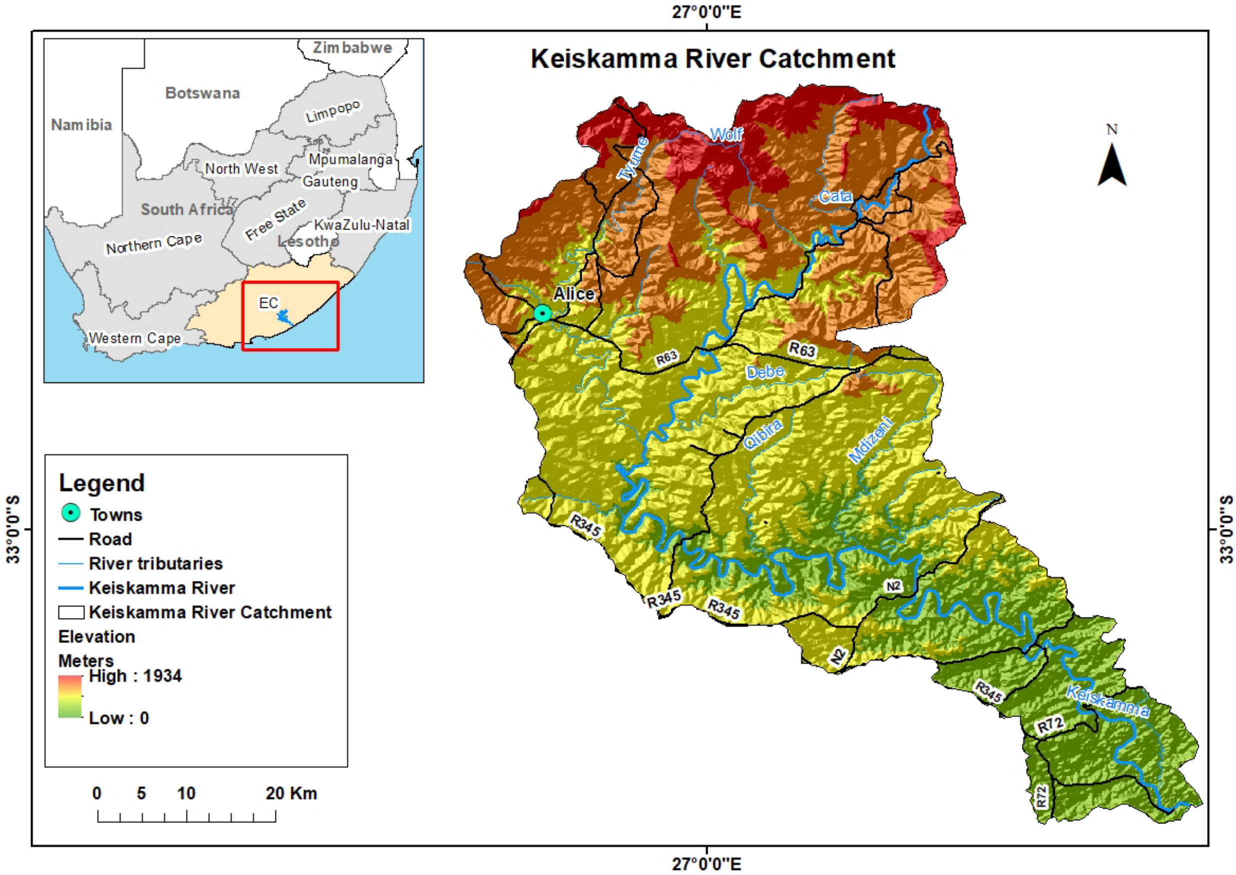

Figure 1.2: Location map of the Keiskamma River catchment

The summer months receive the highest precipitation, whereas June and July are the driest winter months (Mhangara, Kakembo, & Lim, 2012). Large areas in the escarpment zone are protected and its land cover conditions can be described as pristine. The average annual temperatures are 11°C in the escarpment zone and 18°C on the coastal plateau (Mhangara, 2011). Temperatures can rise and fall to 38°C and -2°C in summer and winter respectively (DWAF, 2004). Summer temperatures regularly exceed 40ºC and cold temperatures are experienced during the winter months with occasional snowfalls in areas between the Amatole mountain range and Keiskammahoek to the Hogsback area (Mhangara, 2011).

The Keiskamma River Catchment exhibits the climatic vulnerability of various catchments on the Eastern Cape coast (Mhangara, 2011). The catchment is explicitly categorised into three topographic zones, namely, escarpment, plateau and coastal zones (DWAF, 2004). The escarpment zone receives higher rainfall and mostly contains protected mountain forests. The plateau zone encompasses communal settlements where land degradation in the form of soil erosion, vegetation invasions and reduction, are among the notable environmental problems. These problems have been aggravated by increased and uncontrolled land-use practices, which have had a major impact on the water quantity and quality of the Keiskamma River. It is necessary to investigate the impacts of land use and land cover changes within the catchment to establish implications on water quality and quantity in key water resources in the catchment. The findings could then be extrapolated to other catchments with similar vulnerability to formulate suitable environmental change and adaptation strategies in the catchments of South Africa.

1.3.3 Mthatha River Catchment

Mthatha River Catchment lies between latitudes 31°36'29.19"S and Longitudes 28°49'30.05"E).

The Mthatha River catchment is located in the T20 tertiary catchment, which lies within the Mzimvubu to Keiskamma Water Management Area (WMA 12) (proposed new WMA is Mzimvubu to Tsitsikamma WMA 7 – Government Gazette 35517, Notice No. 547, 20 July 2012). Mthatha river catchment is situated in King Sabata Dalindyebo and Nyandeni Local Municipalities of the O.R Tambo District Municipality in the Eastern Cape Province. The perennial Mthatha river originates in the Drakensberg at 1400 m elevation, is approximately 250 km long and 50 km wide and it covers an area of about 5 520 km^2. Mthatha River Catchment consists of the main river (Mthatha River) which is approximately 250 km long and two large tributaries wind their way to the sea north of Coffee Bay.

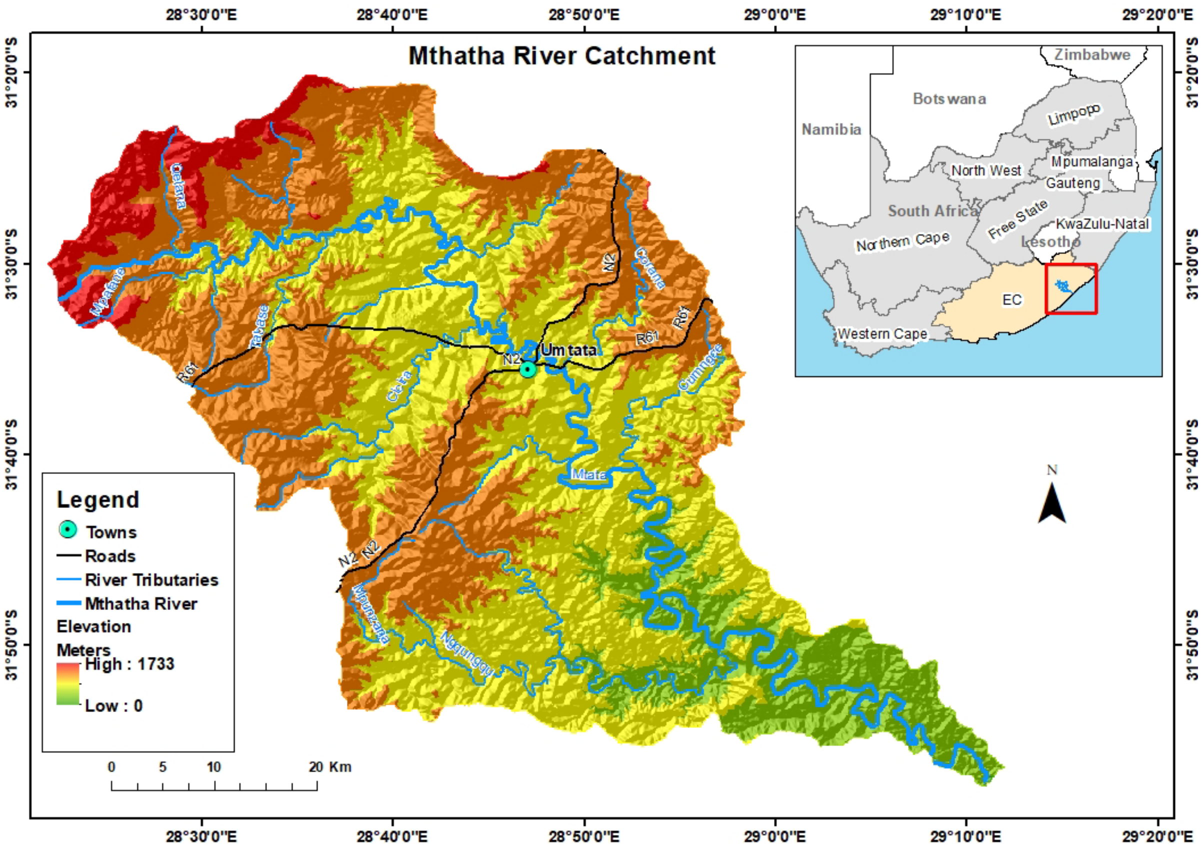

Figure 1.3: Location map of the Mthatha River catchment

The catchment comprises predominantly mountainous and valley tops. The vegetation is largely grassland with some natural and commercial plantations. The topography of the King Sabata Dalindyebo and Nyandeni Municipalities is incised with large river valleys and floodplains that run on a northwest-southeast axis. The inland areas, which typify the study site, could be described as undulating to hilly, with moderate to steep slopes. The landscape is interspersed with grassland areas and patches of forest, with the river valleys covered by a thicket. The upper catchment area includes the Mthatha River headwaters and the Qelana tributary. The uppermost regions of the headwaters are still in a natural state as they are not accessible to humans and cattle. The upper reaches are mainly covered by commercial forest plantations. Commercial water use is dominated by forestry-related industries (Langeni and KwaBhaca sawmills), followed by the industrial, urban and rural sectors.

The agricultural sector is underdeveloped within the basin, with scattered small-scale subsistence irrigation schemes using water pumped straight from the rivers, mainly in the middle and lower sections of the catchment (DWAF, 2008). The Mthatha town is located in the middle reaches of the catchment and is predominately covered by built-up areas, factories and industries. Informal settlements naturally cluster near employment opportunities, such as the timber mills in Ugie and Mthatha towns. Patches of grassland are open for grazing. Subsistence farming and forestry are the main landuse in the catchment. A few natural areas exist, mainly around the steep valleys towards the coast (DWAF, 2008).

Mthatha Dam is the major water storage reservoir in the Mthatha catchment of the Mthatha River. This dam has a catchment area of 886 km^2 and can store up to 254 million m^3 of water while yielding about 14,5 million m^3 of water a year. Mthatha Dam supplies Mthatha town and the surrounding areas with domestic water and acts as balancing water storage, supplying the small dams at First and Second Falls downstream of Mthatha town (DWAF, 2008). Major landuse types in the Mthatha river catchment area are water bodies, forest plantations, built-up areas, cultivated lands, natural forests, and grasslands.

1.4 Methodology

1.4.1 Field data collection

Fieldwork was conducted in each catchment from the 1st of October to the 25th of December 2020, matching the dates that remotely sensed data were acquired for the three study locations. Google earth and existing 2018 land cover maps of South Africa prepared by the Department of Environment Affairs (DEA) were used to navigate the field sites. Once the sample sites were located, different land cover classes were identified, using visual observations with an aid of the existing 2018 land cover map of South Africa (DEA). Land cover classes that were identified (Table 1.1) include water bodies, bare land, built-up, forest, cultivated lands, etc. A 90 x 90 m plot was randomly demarcated at the centre of each relatively homogeneous land cover class (e.g. grasslands) to avoid possible spectral mixing during classification. Coordinates were then recorded at the centre of each plot at a sub-meter accuracy using Garmin GPS to validate satellite remote sensing data (Sepuru and Dube, 2018). Google Earth was also used to generate ground-truthing data for historical image classifications (1994, 2000, 2005, 2010, and 2019) and also clearly distinguishable regions that were not easily accessible like mountainous areas, protected forests and water bodies. During the field data campaign, 1800 (200 per class) GPS points were recorded. These GPS points were used to extract spectral data from the satellite data sets across the three study areas. The collected data was split into training datasets, which were then used for supervised classification of the entire images, and validation datasets which were used to evaluate classification accuracy. It is important to note that the datasets need to be spread evenly over the research area (Mohammady et al., 2014), about 70% was used as training dataset and 30% was used as validation data. The validation data was roughly matched to be representative of the study area (Christoph et al., 2016). Furthermore, geo-located hand-held camera photographs were acquired for each sample site and a detailed description of what was observed and recorded on a land overland cover site data collection sheet. After a detailed characterisation of cover types in all sample sites, the compiled field data were captured in an excel spreadsheet in which numbered-class-labelled sites and photo standards were relationally linked to their coordinate locations.

Table 1.1: Glossary or Land cover classes

CLASS NAME	CLASS	DESCRIPTION
Cultivated lands	1	Maize, vegetables
Built-up	2	Buildings, roads
Plantations	3	Citrus, Pines, tropical fruits
Water bodies	4	Dams, rivers
Bare surfaces	5	Rocks, bare soils
Grasslands	6	Rangelands
Natural forests	7	Dense/Sparse trees
Shrublands	8	Short trees
Wetlands	9	Vegetated/swampy areas
Burn scars	10	Burnt areas

From the above land cover classes (Table 1.1), six major LULC classes were derived for the Keiskamma and Mthatha river catchments namely: *agriculture, bare land, built-up areas, vegetation, and water bodies*. However, for the Letaba catchment, nine major LULC classes were extracted namely: *bare surfaces, built-up, burn scars, cultivated lands, grasslands, plantations, natural forests, shrublands, and water bodies*. This aggregation was reasoned to be suitable for this investigation because it encompassed the inability of Landsat imagery's coarse 30-m spatial resolution to distinguish sub-pixel sized cover types comprising different vegetation species without compromising the main objective of the investigation.

1.4.2 Satellite data acquisition and processing

Cloud-free Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 OLI images were used for the characterization of historical and current land use and cover types in Letaba, Mthatha, and Keiskamma river catchments. The criteria for satellite imagery selection was that the scenes must contain little or no clouds and haze. Another criterion for the selection of the satellite

imagery was that they must be from the same year and where possible the same season, especially in cases whereby more than two scenes or tiles were needed to perform image mosaicking (e.g. Letaba River catchment). This was done to eliminate solar radiation differences and shades since they may affect image classification accuracies.
Landsat 5 satellite was launched on 1 March 1984 and decommissioned on 5 June 2013. Landsat 5 provides global moderate-resolution measurements of the earth's surface for almost 29 years. The satellite carried the two-whiskbroom instruments: (i) Thematic Mapper (TM) with seven spectral bands, including a thermal band and (ii) Multispectral Scanner (MSS) with four spectral bands. Landsat 7 satellite was launched on April 15, 1999, carrying Enhanced Thematic Mapper (ETM+) sensor (whiskbroom instrument), with eight spectral bands, including a panchromatic and thermal band. Since June 2003, Landsat 7 ETM+ whiskbroom instrument acquired and provided images with gaps caused by Scan Line Corrector (SLC) failure.

Landsat 8 acquires information about the earth's surface with a moderate resolution instrument in the visible, near-infrared, shortwave, and thermal infrared. The sensor was launched on the 11th of February 2013, carrying two push broom instruments: (i) The Operational Land Imager (OLI) consisting of nine spectral bands and (ii) The thermal Infrared Sensor (TIRS) which includes thermal bands 10 and 11 at a 100 m spatial resolution. Table 1.2 summarises the spectral characteristics of the images used in this study. All Landsat images were downloaded from the USGS Earth Resources Observation (http://earthexplorer.usgs.gov/). The Landsat images have the advantages of being freely accessible and are available for repeated seasonal images over a short period (16-days temporal resolution). These were very useful for monitoring the subtle differences in land cover changes around the area of interest. The two satellite images were used to map land cover and use types and changes within the three catchments.

Table 1.2: Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 OLI spectral characteristics used in this study

Landsat 8 OLI		**Landsat 7 ETM+**		**Landsat 5 TM**		
Bands	**Wavelength (μm)**	**Bands**	**Wavelength (μm)**	**Bands**	**Wavelength (μm)**	**Resolution (m)**
Band 1 – Coastal aerosol	0.43-0.45	**n/a**	—	**n/a**	—	30
Band 2 – Blue	0.45-0.51	**Band 1**	0.45-0.52	**Band 1**	(0.45-0.52 μm)	30
Band 3 – Green	0.53-0.59	**Band 2**	0.52-0.60	**Band 2**	(0.52-0.60 μm)	30
Band 4 – Red	0.64-0.67	**Band 3**	0.63-0.69	**Band 3**	(0.63-0.69 μm)	30
Band 5 – Near infrared (NIR)	0.85-0.88	**Band 4**	0.77-0.90	**Band 4**	(0.76-0.90 μm)	30
Band 6 – Shortwave Infrared(SWIR 1)	1.57-1.65	**Band 5**	1.55-1.75	**Band 5**	(1.55-1.75 μm)	30
Band 7 – Shortwave Infrared(SWIR 2)	2.11-2.29	**Band 7**	2.09-2.35	**Band 7**	(2.08-2.35 μm)	30

Band 8 – Panchromatic	0.50-0.68	**Band 8**	0.52-0.90	**n/a**	—	15
Band 9 – Cirrus	1.36-1.38	**n/a**	—	**n/a**	—	30
Band 10 – **Thermal infrared (TIRS) 1**	10.60-11.19	**Band 6**	10.40-12.50	**Band 6**	(10.40-12.50 µm)	TIRS/ETM +
Band 11 – **Thermal infrared (TIRS) 2**	11.50-12.51	**—**	—		—	100/60 * (30)

A detailed summary of satellite images used in this study is provided in Table 1.3.

Table 1.3: Summary detail of the satellite datasets used for LULC mapping.

Catchment	Satellite data	Acquisition date	Landsat product	Path/Row
Mthatha	**Landsat 7 ETM+**	09/10/2000	LE07_L1TP_169082	169/082
	Landsat 7 ETM+	06/01/2010	LE07_L1TP_169082	169/082
	Landsat 8 OLI	04/09/2019	LC08_L1TP_169082	169/082
Keiskamma	**Landsat 7 ETM+**	19/12/2000	LE07_L1TP_170083	170/083
	Landsat 7 ETM+	25/08/2010	LE07_L1TP_170083	170/083
	Landsat 7 ETM+	10/08/2019	LC08_L1TP_170083	170/083
Letaba	**Landsat 5 TM**	13/12/1994	LT05_L1TP_168076	168/076
	Landsat 5 TM	13/12/1994	LT05_L1TP_168077	168/077
	Landsat 5 TM	20/12/1994	LT05_L1TP_169076	169/076
	Landsat 5 TM	20/12/1994	LT05_L1TP_169077	169/077
	Landsat 5 TM	20/07/2005	LT05_L1TP_168076	168/076
	Landsat 5 TM	20/07/2005	LT05_L1TP_168077	168/077
	Landsat 5 TM	16/11/2005	LT05_L1TP_169076	169/076
	Landsat 5 TM	13/09/2005	LT05_L1TP_169077	169/077
	Landsat 8 OLI	15/09/2020	LC08_L1TP_168076	168/076
	Landsat 8 OLI	13/09/2020	LC08_L1TP_168077	168/077
	Landsat 8 OLI	11/12/2020	LC08_L1TP_168076	168/076
	Landsat 8 OLI	11/12/2020	LC08_L1TP_169077	169/077

All images were georeferenced based on ground control points developed from the existing topographical map of the three study areas. The images were projected to UTM projection (WGS84) using standard procedures in the ArcMap 10.6 geometric correction tool. The nearest neighbour resampling algorithm was used because, in this resampling method, the pixels are not averaged as compared to cubic convolution or bilinear interpolation methods (Teferi et al., 2010). Atmospheric corrections were done using the dark object subtraction (DOS1) model in QGIS (Sepuru and Dube, 2018). Image mosaicking and subsetting were done based on the requirements of each study area.

1.4.3 Supervised classification and classification accuracy assessment

Supervised classification using the maximum likelihood classifier algorithm was used for land cover classification in a geospatial environment. Maximum likelihood classification (MLC) is a common parametric algorithm extensively used for identifying major LULC classes (Huang et al., 2002; Gašparovic et al., 2019; Verma et al., 2020). A supervised classification approach requires training data composed of reference samples of known land cover classes to increase classification accuracy (Verma et al., 2020). Ground control points constituting 70% of the data was randomly selected as training samples, and the remaining 30% were used as validating samples.

The maximum likelihood classifier (MLC) embedded in ArcMap 10.6 was then selected for the land cover classification of Landsat data. The MLC is one of the popular parametric classifiers based on the Bayes theorem used for the supervised classification of remote sensing data (Otukei and Blaschke, 2009; Foody et al., 1992). It makes use of a discriminant function to assign pixels to the class with the highest likelihood. Class mean vector and covariance matrix are the key inputs to the function and can be estimated from the training pixels of a particular class. Assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class. Each pixel is assigned to the class that has the highest probability (that is, the maximum likelihood). In the maximum-likelihood classification, pixels are allocated to their most likely class of membership (Foody et al., 1992). The Bayesian equation is used to present the maximum likelihood classification algorithm as follows:

$$D = \text{In}(a_c) - [0.5\ \text{In}\ (|cov_c|)] - [0.5(X - M_c)\ T\ (cov_c - 1)\ (X - M_c) \quad \text{.......[1]}$$

D denotes the weighted distance or likelihood of unknown measurement vector X, which belongs to one of the known classes Mc (Otukei and Blaschke, 2009). Whereas, cov_C represents the covariance matrix.

Image classification was carried out using a maximum likelihood algorithm. For Keiskamma and Mthatha river catchments, six major LULC classes namely; agriculture, bare land, built-up areas, vegetation, and water bodies were extracted and classified. For the Letaba catchment, nine major LULC classes that were extracted and classified were: bare surfaces, built-up, burn scars, cultivated lands, grasslands, plantations, natural forests, shrublands, and water bodies.

The accuracy of LULC classification is a prerequisite for achieving accurate image classification output. Comparing the classified image to the ground truthing data is a way of performing an accuracy assessment (Jensen, 1996). There is a disagreement between the ratios of study and training sets of land cover types for classification accuracy evaluation. Since the reference data was split into 70% for classification and 30% for validation. About 60 (30%) samples out of 200 were used for accuracy assessments for each land cover class in each river catchment. The derived accuracies in the form of cross-tabulation matrices, using the allocation technique that was developed by Pontius & Millones (2011) were used to compute overall accuracy, producer accuracy, user accuracy for each of the three map outputs for each catchment and determination of kappa coefficients (K). User's accuracy is a measure of how well the classification is performed. It indicates the percentage of probability that the class, which a pixel is classified on an image, actually represents that class on the ground (Ahmad & Quegan, 2012). It is calculated by dividing each of the diagonal elements in a confusion matrix by the total of the row in which it occurs. The producer's accuracy is a measure of the accuracy of a particular classification scheme and shows the percentage of a particular ground class that is correctly classified (Ahmad & Quegan, 2012). Overall accuracy is calculated by measuring the number of corrected classified pixels and then dividing by the total number of pixels. The Kappa coefficient is calculated by multiplying the total pixels in all the ground truth classes by the sum of confusion matrix diagonals then subtracting the sum of ground truth pixels in class times and the sum of classified pixels in that class summed over all classes finally dividing by the entire pixels (Ahmad & Quegan, 2012).

1.4.4 Land cover /use Change detection

To understand the rate of changes for different land cover types within the three selected catchments mathematical computations were undertaken. Firstly, the area covered by each class for each year was computed, using spatial analyst tools in a GIS environment. This information was then used to determine the rate changes over the years. The same data was further analysed to determine the trends in the observed changes.

1.4.5 Statistical Analysis

Trend coefficients were computed to determine the direction of observed changes in different land cover types. The trend coefficients were verified by executing the Mann-Kendall (M-K) test using XLSTAT to calculate the Sen Slope Estimate (SSE) for each land cover type with statistical significance being determined by calculating p values at $\sigma = 0.05$.

The Mann-Kendall test has been widely used in land cover change mapping for trend detection (Martínez & Gilabert, 2009; Setyorini et al., 2017; Priyadarshi et al., 2020) and has been described as a more reliable method for detecting change-trends in the analysis of remote sensing data (Militino et al., 2020).

The M-K test is a non-parametric test for identifying trends in time series data by comparing the relative magnitudes of sample data rather than the data values themselves (Kendall, 1948; Mann, 1945) while the SSE provides objective estimates of the magnitude of trends (Sen, 1968) in the long term temporal data. A positive (negative) SSE indicates an upward (downward) trend while its magnitude indicates steepness (Militino et al., 2020). The key benefits of the M-K test are that apart from being able to show whether a trend has been stationary, decreasing or increasing, it does not require that the data should follow any specific type of distribution (Militino et al., 2020). The M-K test is not sensitive to unexpected breaks in datasets due to inhomogeneous time series (Akpoti et al., 2016). At a 5% significance level, if the *p*-value <= σ 0.05, then the alternative hypothesis is accepted which signifies the presence of a trend in the data and if the *p*-value is >= σ 0.05, then H_0 will be accepted that denotes the absence of a trend in the data.

1.4.6 Summary of the methodology

Figure 1.3 provides a flowchart of the methodology adopted in mapping land cover changes in the three catchments.

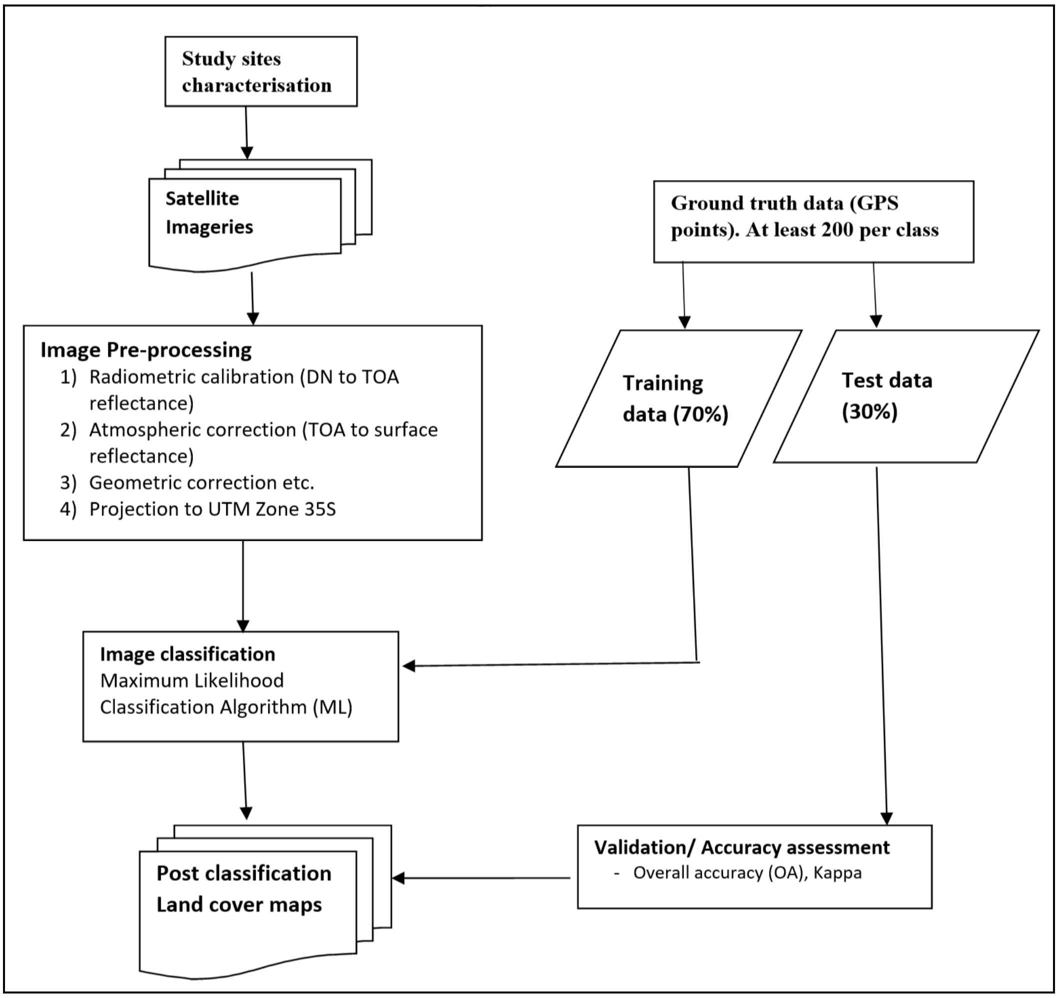

Figure 1.3: Flowchart detailing image analysis steps undertaken

1.5 Results

Results of this project are presented in the form of a) land cover change maps for each of the three catchments (Figures 1.5, 1.6, and 1.7); b) accuracy assessment tables for each catchment satellite-derived land cover maps (Tables 1.4, 1.5 and 1.6); c) tables (Tables 1.7, 1.8 and 1.9) that shows percentage changes in information classes that were mapped; d) graphs (Figures 1.8 and 1.9) that show temporal variations in the spatial distributions of these land cover types; e) tables (Table 1.10, 1.11 and 1.12) that reflect on the statistical analysis of the results.

1.5.1 Spatial and temporal distribution of Land Use and Land Cover

Figure 1.5 illustrates land cover change maps for the Mthatha catchment for the period between 2000 and 2019. It can be observed that bare lands occupied a huge surface area for the period between 2000 and 2019 when compared to other land cover classes. Bare lands occupied the largest surface area of 162 468 hectares in 2010, with a minor decrease observed in 2019 (158 943 ha) and the lowest surface area observed in 2000 (128 758 ha) (Table 1.7). This can be attributed to seasonal variations since some bare lands are turned into agricultural lands and vegetation regrowth, especially during the rainy season. The results in Figure 1.5 also indicate that agriculture is the second-largest predominant land use/cover type in the Mthatha catchment. For example, in 2000, agriculture occupied the largest surface area of 7118 ha when compared with other years under study. Whereas, in 2010 agriculture occupied the lowest (3843 ha) surface area when compared with bare lands, built-up areas, vegetation and water bodies for the same year (Table 1.7). Vegetation was observed to be the third-largest predominant land cover type in the Mthatha catchment for all the years under study (Figure 1.5). Figure 1.5a shows that most of the vegetation was concentrated in the North West and South East of the Mthatha river as well as areas along the rivers in 2000. Through the visual interpretation of the land cover/use maps in Figure 1.5, there has been a slight decrease in vegetation cover between 2000 to 2019, especially in the South Eastern region of the Mthatha river catchment. For instance, in 2000 vegetation occupied an area of 41344 ha, then decreased to 26918 ha in 2019, then 26645 ha in 2010, respectively. Strikingly, built-up areas are the lowest land cover/use type that is found around the Mthatha river catchment as of 2019 (Figure 1.5c), occupying approximately a surface area of 4758 ha, followed by water bodies occupying a surface area of 4758. The results of the study show a dramatic decrease in the surface area of water bodies from 2000 to 2019, changing from 14152 ha to 4758 ha (Table 1.7) in a space of 19 years (Figure 1.5).

Figure 1.6 illustrates land use and land cover maps and changes in the Keiskamma catchment for the period between 2000 and 2019. The results indicate that bare lands, vegetation cover and built-up areas are the most predominant land cover type found in the Keiskamma catchment occupying a combined total area of approximately 254368 ha in 2019. Whereas, the least predominant land cover type found around the Keiskamma catchment is water bodies and agricultural activities which cover the lowest combined surface area of 15038 ha, each contributing around 3929 ha (agriculture) and 11109 ha (water bodies). The results of the study also show an observable increase in agricultural activities for the 19 years (Figure 1.6), especially in the southwestern region of the Keiskamma catchment and along the river tributaries. Built-up areas have also increased from 7778 ha to 15435 ha during the 19 years, especially in the eastern part of the catchment (Table 1.8). Similarly, water bodies have also increased from 8125 ha to 11109 ha during the study period, specifically in the southern region of the catchment (Figure 1.6c).

Furthermore, Figure 1.7 portrays land use and land cover distribution maps for the Letaba catchment for the period between 1994 and 2020. According to the information revealed by classification results in Figure 1.7, the predominant land cover/use type that is found around the Letaba river catchment is shrublands that consist of short and dense trees. This land cover type is highly concentrated in the northern region of the Letaba river catchment, which occupied an area of approximately 361975 ha in 1994, and decreased to 290406 ha in 2020. The results also show that bare surfaces in 1994 used to be the second most dominant land cover type in the Letaba catchment but gradually decreased towards 2020. The land cover/use type that gained dominance, while bare surfaces were losing dominance was observed to be built-up areas, which increased from 5481 ha in 1994 to 118476 ha in 2020, and this is arguably a huge increase. According to the results of the study (Figure 1.7), the natural forest is the third predominant land cover type that is found Letaba river catchment recently (2020), occupying a surface area of approximately 118029 ha, compared to 221885 ha observed in 2005. Natural forests can be observed both in the upper, middle and lower levels of the Letaba river catchment when moving from East to West (Figure 1.7). The classified maps also show that the cultivated lands have been declining from 1994 to 2020. Whereas, plantations have faced an increment in the total area from 1994 to 2020. Both water bodies (1152 to 12721 ha) and grasslands (1152 to 12721 ha) were observed to have increased in surface area around the Letaba catchment during a period of 26 years (Table 1.8). Another striking land cover type found around the Letaba river catchment is burnt scars and this shows a clear indication of frequent fire occurrences around the study area. Just like other land cover classes; there have been some fluctuations in terms of the size of the burnt areas. For instance, a classified map of 1994 (Figure 1.7a) shows that burnt areas covered surface areas of approximately 54856 ha, which is huge when compared to 2005 which observed only 16225 ha of burned areas. However, based on the results of the study, the burnt area has since increased again in 2020 to approximately 32478 ha.

The accuracy levels of the classifications were assessed for the supervised classification for each catchment based on the ground truth data (Tables 1.4, 1.5, and 1.6). For the Keiskamma catchment, the overall classification accuracies and Kappa coefficients (K) were 57.75%; K = 0.16 for 2000, 72.25%; K = 0.45 for 2010, and 70.25%; K=0.41 for 2019 (Table 1.5). For the Mthatha catchment (Table 1.4), the overall classification accuracies and Ks were 77.83%; K = 0.56 for 2000, 76.67%; K = 0.53 for 2010, and 83.33%; K = 0.67 for 2019. For the Letaba catchment (Table 1.6) the overall classification accuracies and Ks were 57,5%; K = 0.64 for 1994, 56,5%; K = 0.62 for 2005, and 72.5%; K = 0.90 for 2020. Although various factors can be solicited to describe why the accuracy levels were less than the 85% benchmark (Foody, 2002), accuracy levels are designated to allow users to establish the suitability of a map for their particular requirements and not to offer a base for assessment of quality (Foody, 2008). This is because map accuracies are not always an exact portrayal of closeness to reality (Congalton and Green, 1993). Similarly, it is also imperative to acknowledge that even though the kappa coefficient is extensively used to classify accuracies, it has a tendency of underestimating accuracies by eliminating chance agreement from the process of quantification (Foody, 2008). Therefore, it is logical to conclude that the accuracy levels of the produced maps were within satisfactory limits.

Table 1.4: Accuracy assessment for the Mthatha catchment satellite-derived land use and land cover map

Accuracy assessment	**2000**	**2010**	**2019**
Kappa coefficient	55.67	53.33	66.67
User’s accuracy	75.33	74.33	81.67
Producer’s accuracy	79.30	77.98	84.48
Overall accuracy	77.83	76.67	83.33

Table 1.5: Accuracy assessment for the Keiskamma catchment satellite-derived land use and land cover map

Accuracy Assessment	2000	2010	2019
Kappa coefficient	15.5	44.5	40.5
User's accuracy	55.5	74	69.5
Producer's accuracy	58.1	71.50	70.56
Overall accuracy	57.75	72.25	70.25

Table 1.6: Accuracy assessment for the Greater Letaba catchment satellite-derived land use and land cover map

Accuracy Assessment	1994	2005	2020
Kappa coefficient	64,4	61,6	89,9
User's accuracy	71,9	70,2	91,8
Producer's accuracy	48,4	51,8	89,0
Overall accuracy	57,5	56,5	72,5

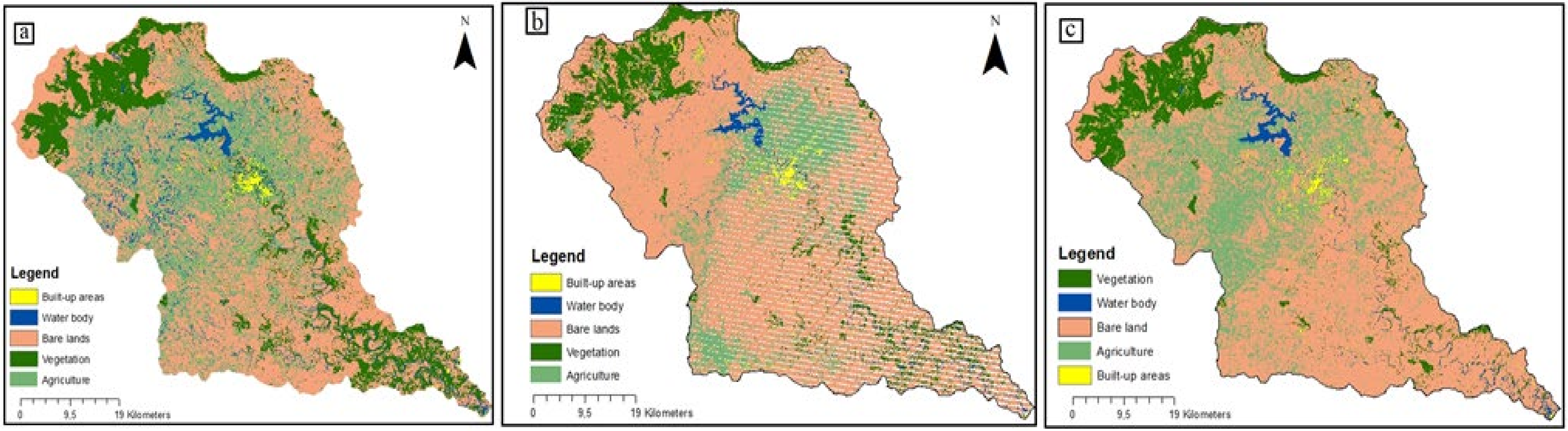

Figure 1.4: Satellite-derived Land use and Land cover changes for the Mthatha catchment for the period between 2000 and 2019

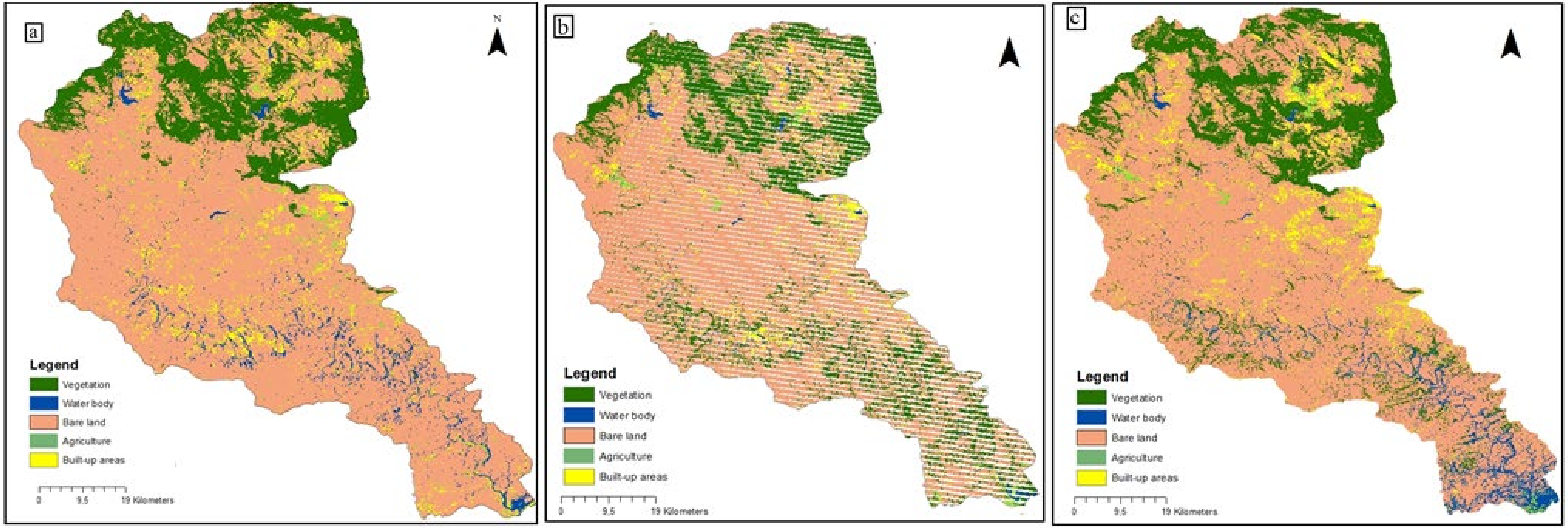

Figure 1.5: Satellite-derived Land use and Land cover changes for the Keiskamma catchment for the period between 2000 and 2019

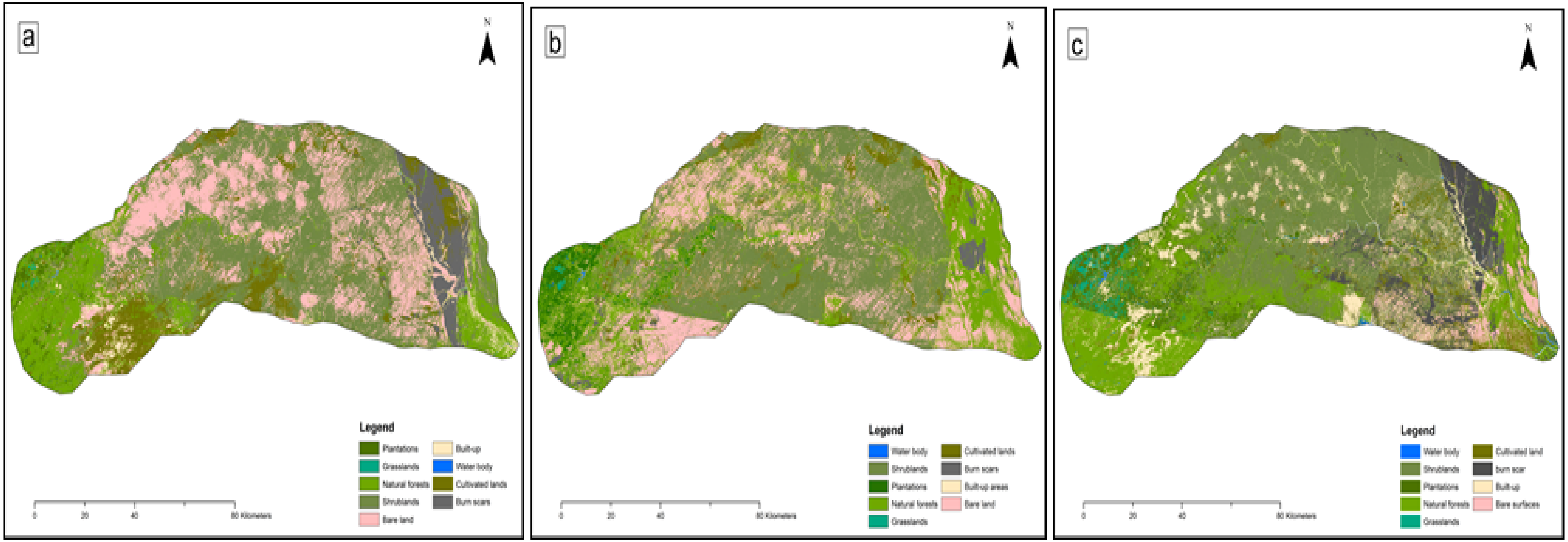

Figure 1.6: Satellite-derived Land use and Land cover changes for the Letaba catchment for the period between 1994 and 2020

1.5.2 Spatial and temporal Change in Land Use and Land Cover

Results of the Mthatha catchment reflected a long-term increase in bare land by 11.72% and a marginal increase in built-up areas (0.52%) (Table 1.7). The time period 2000-2010 had the biggest increase in bare lands (13.09%) followed by a major decline in agriculture, vegetation and water bodies. Built-up areas covered the smallest area in comparison to other land cover types and had the least changes overall (Figure 1.8). There is a declining trend in water bodies within the catchment since the year 2000, which also attributes to the observed increase in bare lands. Water bodies were the only land cover type with a persistent decrease during the entire period.

Table 1.7: **Satellite-derived area per LULC per year for Mthatha catchment**

Class name	Area (ha)			%age composition			%age change		
	2000	2010	2019	2000	2010	2019	2000-2010	2010-2019	2000-2019
Agriculture	71 118	38 432	63 181	27,61	14.92	24,53	-12,69	9,61	-3,08
Bare land	128 758	162 468	158 943	49,98	63,07	61,70	13,09	-1,37	11,72
Built up areas	2 365	2 845	3 701	0,92	1,10	1,44	0,19	0,33	0,52
Vegetation	41 344	26 645	26 918	16,05	10,34	10,45	-5,71	0,11	-5,60
Water bodies	14 152	4 914	4 758	5,49	1,91	1,85	-3,59	-0,06	-3,65
Total area mapped (ha)	257 609	257 609	257 609	---	---	---	---	---	---

Results of the Keiskamma catchment point to marginal long-term changes in most cover types to be an increase of not more than 3%, with the only exception being bare land which declined by about 3.32% (Table 1.8). Agriculture decreased by approximately 0.2% in the first 10 years of the 19 years, after which agriculture increased by about 0.30% between 2010 and 2019 (Table 1.8). Agriculture covered the smallest area in comparison to other land cover types and had the least changes overall (Figure 1.8). Built-up areas were the land cover type that had the highest increase of 2.84% during the observed 19-year period.

Table 1.8: **Satellite-derived area per LULC per year for Keiskamma catchment**

Class name	Area (ha)			%age composition			%age change		
	2000	2010	2019	2000	2010	2019	2000-2010	2010-2019	2000-2019
Agriculture	3 547	3 117	3 929	1,31	1,15	1,46	-0,16	0,30	0,14
Bare land	199 127	154 891	190 154	73,74	57,36	70,42	-16,38	13,06	-3,32
Built up areas	7 778	14 035	15 435	2,88	5,20	5,72	2,32	0,52	2,84
Vegetation	44 574	53 395	48 779	16,51	19,77	18,06	3,27	-1,71	1,56
Water bodies	8 125	2 934	11 109	3,01	1,09	4,11	-1,92	3,03	1,11
Total area mapped (ha)	270032	270032	270032	--	--	--	--	--	--

Results of the Letaba catchment indicate a major long-term (1994-2020) decline in bare surfaces (-19.47%) and a major increase in built-up areas (12.18%) (Table 1.9). Shrublands and bare surfaces are the only land cover types noted by persistent declines during the two-time slices. Plantations, built-up areas and water bodies had a persistent increase during the observed time slices (Figure 1.9).

Table 1.9: **Satellite-derived area per LULC per year for Letaba catchment**

	Area (ha)			%age composition			%age change		
Class name	1994	2005	2020	1994	2005	2020	1994-2005	2005-2020	1994-2020
Bare surfaces	228190	222590	47599	24,60	24,00	5,13	-0,60	-18,87	-19,47
Built-up	5481	25169	118476	0,59	2,71	12,77	2,12	10,06	12,18
Burn scars	54856	16225	32478	5,91	1,75	3,50	-4,16	1,75	-2,41
Cultivated lands	98682	58508	63852	10,64	6,31	6,88	-4,33	0,58	-3,75
Grasslands	1152	12350	12721	0,12	1,33	1,37	1,21	0,04	1,25
Natural forests	137000	221885	118029	14,77	23,92	12,72	9,15	-11,20	-2,05
Plantations	17267	36267	65088	1,86	3,91	7,02	2,05	3,11	5,16
Shrublands	361975	361708	290406	39,02	38,99	31,31	-0,03	-7,69	-7,72
Waterbodies	717	1110	1889	0,08	0,12	0,20	0,04	0,08	0,13
Total area mapped (ha)	927593	927593	927593	---	---	---	---	---	---

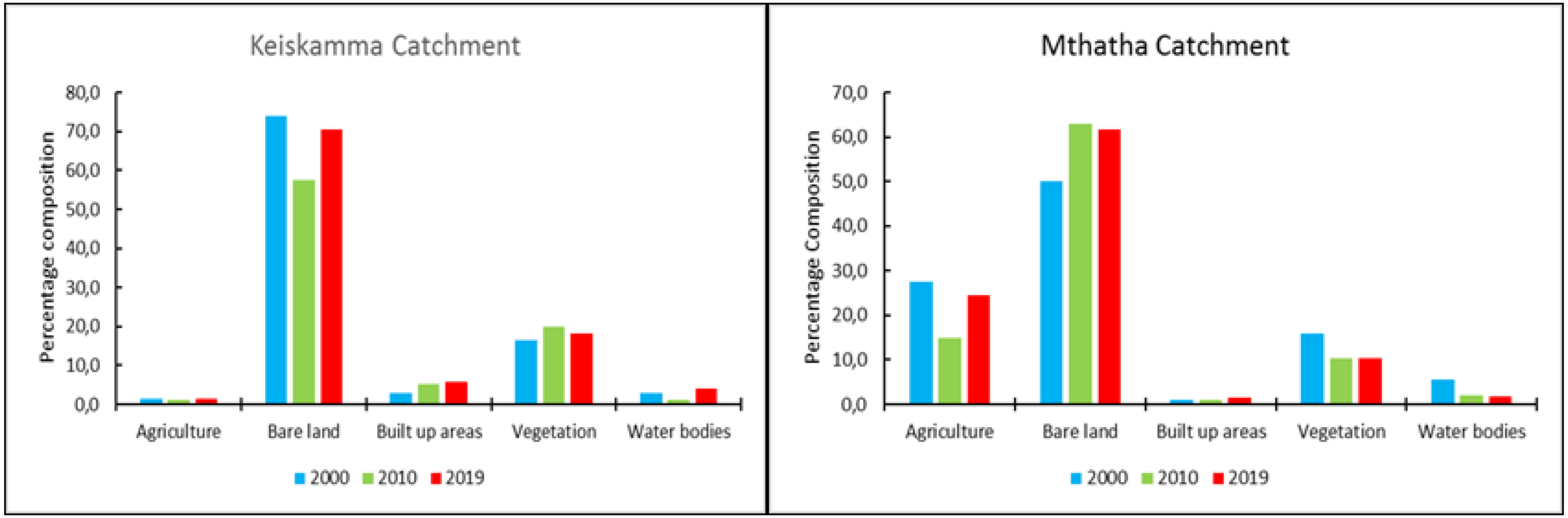

Figure 1.7: Temporal variations in the spatial distribution in different land cover types within the Keiskamma and Mthatha catchments

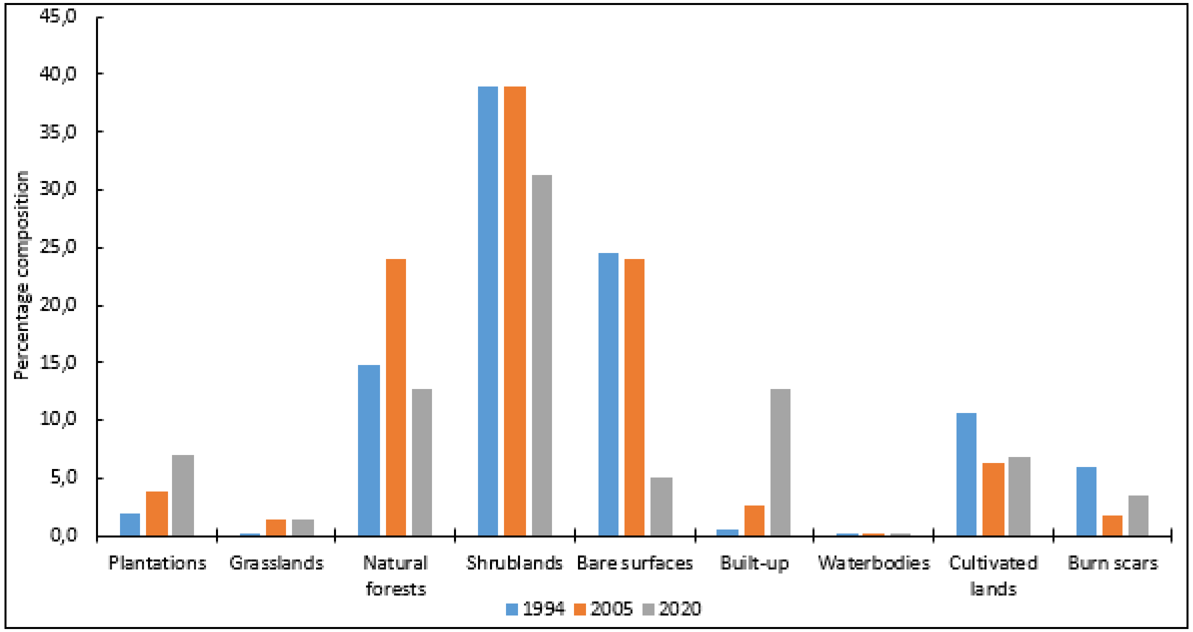

Figure 1.8: Temporal variations in the spatial distribution of different land cover types within the Letaba catchment

Although the previously presented graphs are useful by offering a visual outlook of the trend of observed changes in different cover types, they have restrictions because visualisation alone cannot sufficiently enumerate the magnitude of a trend. Hence, individuals have a tendency of focusing on outliers so that strong variation can mask trends while gradual changes are difficult to detect from visual inspection. However, to overcome this limitation, the direction of change for each cover type was objectively determined through statistical analysis.

Table 1.10 summarises the results of the statistical analyses that were performed as described above for the Mthatha Catchment. Simple linear trend analysis revealed negative trends for agriculture, vegetation and water bodies, and positive trends for bare land and built-up areas. These observations were in agreement with the SSE values.

Table 1.10: **Linear trend coefficients, Sen Slope Estimates and *p* values for observed changes in land cover types in Mthatha Catchment between 2000 and 2019.**

Cover type	Linear trend coefficient	R^2	Sen Slope Estimate (SSE)	*p*-value
Agriculture	y = -1,5405x + 25,432	R^2 = 0,05	-0,162	*1,000
Bare land	y = 5,8587x + 46,532	R^2 = 0,66	0,617	**1,000
Built up areas	y = 0,2593x + 0,6344	R^2 = 0,97	0,027	** 0,296
Vegetation	y = -2,8x + 17,88	R^2 = 0,74	-0,295	*1,000
Water bodies	y = -1,8233x + 6,7293	R^2 = 0,76	-0,192	*0,296

Interpretation: No trend if the *p*-value is > 0.05; negative SSE = declining trend and vice versa
*Declining but not significant; **Increasing but not significant

Table 1.11 summarises the results of the statistical analyses that were performed as described above for the Keiskamma Catchment. Simple linear trend analysis revealed negative trends for bare land and positive trends for the rest of the land cover types while the SSE also revealed a declining trend for bare land only (SSE= -0,175).

Table 1.11: **Linear trend coefficients, Sen Slope Estimates and p values for observed changes in land cover types in Keiskamma Catchment between 2000 and 2019**

Cover type	Linear trend coefficient	R^2	Sen Slope Estimate (SSE)	*p*-value
Agriculture	y = 0,0707x + 1,1662	R² = 0,22	0,007	**1,000
Bare land	y = -1,6615x + 70,497	R² = 0,04	-0,175	*1,000
Built up areas	y = 1,4178x + 1,7624	R² = 0,88	0,149	**0,296
Vegetation	y = 0,7786x + 16,558	R² = 0,23	0,082	**1,000
Water bodies	y= 0,5525x + 1,6314	R² = 0,13	0,058	**1,000

Interpretation: No trend if the *p*-value is > 0.05; negative SSE = declining trend and vice versa

*Declining but not significant; **Increasing but not significant

Table 1.12 summarises the results of the statistical analyses that were performed as described above for the Letaba Catchment. Simple linear trend analysis revealed positive trends for built-up areas, grasslands, plantations, and water bodies. We also observed negative trends for bare surfaces, burn scars, cultivated lands, natural forests and shrublands.

Table 1.12: **Linear trend coefficients, Sen Slope Estimates, and *p* values for observed changes in land cover types in Letaba Catchment between 1994 and 2020**

Cover type	Linear trend coefficient	R^2	Sen Slope Estimate (SSE)	*p*-value
Bare surfaces	y = -9,7344x + 37,378	R² = 0,77	-0,749	*0,296
Built-up	y = 6,0908x - 6,8226	R² = 0,88	0,469	**0,296
Burn scars	y = -1,2062x + 6,1339	R² = 0,33	-0,093	*1,000
Cultivated lands	y = -1,8774x + 11,698	R² = 0,64	-0,144	*1,000
Grasslands	y = 0,6236x - 0,3049	R² = 0,77	0,048	**0,296
Natural forests	y = -1,0226x + 19,183	R² = 0,03	-0,079	*1,000

Plantations	y = 2,5777x - 0,8927	R^2 = 0,99	0,198	**0,296
Shrublands	y = -3,8578x + 44,157	R^2 = 0,75	-0,297	*0,296
Waterbodies	y = 0,0632x + 0,0072	R^2 = 0,97	0,005	**0,296

Interpretation: No trend if the *p*-value is > 0.05; negative SSE = declining trend and vice versa
*Declining but not significant; **Increasing but not significant

For the Mthatha catchment, changes in all cover types between 2000-2019 were not statistically significant at σ = 0.05 (Table 1.10). The increase in bare land by 11.72% and the decrease in vegetation, water bodies and agriculture (Table 1.7) could signify that the climatic conditions are deteriorating owing to reduced rainfall.

Although changes in all cover types in the Keiskamma catchment were not statistically significant at σ = 0.05 (Table 1.11), the persistent expansion of built-up areas by 2.84% (Table 1.8) and inversely related decrease in bare land by 3.32% provide a convenient entry point for interrogating the major drivers of changes in other cover types. Human activities may have largely contributed to the observed decrease in bare land, because of the conversion of bare land of the catchment for residential and other development activities. This continued increase in built-up areas will have effects on the water quality and quantity within the catchment.

For the Letaba catchment, changes in all cover types between 2000-2019 were not statistically significant at σ = 0.05 (Table 1.12).

1.6 Summary and conclusions

Using remote sensing data, the study revealed that the predominant land use/land cover types in the three study areas are agricultural lands, urbanised areas, plantations, water bodies, bare surfaces, grasslands, natural forests, and shrublands. Burned areas were also detected in the Letaba river catchment, even though field fires occur seasonally and sometimes due to berg winds in this particular region, leaving burn scars. All land cover/use types in the three catchments were successfully classified using Landsat time-series data over the observed 19-year (Mthatha and Keiskamma catchment) and 26-year periods (Letaba catchment). The results showed that the overall classification accuracy across the three study areas ranged from 83.33% to 56,5% for the years 2000 and 1994, respectively. The highest overall classification accuracy across the three study areas was observed in the 2019 and 2020 classifications. Mthatha and Keiskamma catchment land cover/use classification maps achieved an overall classification accuracy level of 83.3% and 70.25%, for 2019 classifications. Whereas, Letaba achieved an overall accuracy level of 72.5% for 2020 classifications. The study also indicated that classification of land cover and land use using moderate-resolution remotely sensed imagery remains a challenging task due to spatial resolution complexity, since, some of the land cover features are too small and undetectable, creating spectral mixing which compromises the classification accuracies. Although there has been a slight shift in different land cover and land use types mapped across the three catchments the study concludes that there were no significant changes over the period of 19 and 26 years studied. However, there is still a need to continuously monitor and assess the impacts and levels of Change in land use/cover around river catchments to safeguard water resources and to detect problems early before they become uncontrollable. Therefore, the recent launch of Landsat 8 and Sentinel 2 as well as the free or open data dissemination policy could provide an opportunity to monitor and map land cover and uses more cheaply and accurately across important river catchments in South Africa. This will aid water resource managers, natural resources managers, and relevant authorities to make informed decisions.

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Chapter 2: Assessing the effect of Land Use and Land Cover Change on water quality and quantity in three catchments in South Africa

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2.1 Abstract

Changes in land use and land cover have a significant impact on the quantity and quality of water, which in turn affects human livelihood. Following the observed changes in land use and land cover within the three catchments, more research was done utilizing spatially explicit earth observation techniques and in-situ techniques to quantify the extent of the impact. Each of the major rivers in the three designated catchments was separated into three unique categories: upper, middle, and lower sections/reaches for water sampling and quality analysis in February 2021. During each survey, water temperature (T) (°C), pH, dissolved oxygen (DOC) (mg/L), electric conductivity (EC; μS/cm), total dissolved solids (TDS;) and salinity(SAL) (ppt) were measured in-situ at each site using a handheld YSI Model 554 Data logger multiprobe. Water sampling locations were recorded at sub-meter accuracy using a hand-held Global Positioning System (GPS) to relate the observed in-situ measurements with the remote sensing data. To model water quality parameters across the three selected river catchments, a medium resolution (10 m) dataset such as Sentinel 2 MSI satellite images corresponding to the month (e.g. February 2021) of fieldwork was acquired freely and processed. A point map of the water sampling areas was created using field data and GPS readings. The points were superimposed on the Sentinel 2 MSI image, and then band values or image spectra were extracted to points. The band values were used to calculate nine water indices including the Normalised Difference Water index (NDVI), Normalised Difference Turbidity Index (NDTI), Land Surface Water Index (LSWI), Automated Water Extraction Index (AWEIsh) and Modified Normalised Difference Water Index (MNDWI) in this study to map water quality and water quantity. To determine the relationship between spectral bands and water indices and water quality parameters, Pearson's correlation coefficient (r) was used. Furthermore, stepwise multiple linear regression was used to model water quality using the Sentinel 2 remote sensing data and in-situ field measurements.

The results indicate a strong correlation (-0,50<r>0,79) between the bands mainly in the visible and red-edge region of the electromagnetic spectrum (2,3,4,5) and in-situ water quality parameters such as DO, EC, TDS, SAL and PH. On the other hand, water indices such as NDTI, LSWI, and AWEIsh1 portrayed strong correlations (-0,50<r> 0,89) with water quality parameters. Furthermore, EC and TDS yielded the best strong regression models using Sentinel 2 band 7, band 8, NDTI, and AWEIsh with coefficient determination (R^2) of 0,84 and 0,87 and RMSE of 20,31 µS/cm and 11,62, respectively. Whereas DO, SAL, T and pH models produced less striking results with R^2 lower than 0,5 (DO and PH) and as high or better than > 0. 55 (SAL and T). The analysis confirmed the pollution (eutrophic and organic matter) status in the three catchments, for the period considered by this research. As a result, careful land planning must be done through the joint operation of local authorities, regional agencies, and regional institutions. Concerning water quantity, the total area covered by water in the Letaba catchment increased by 717 ha in 1994 to 1889 ha in 2020, increasing the percentage composition of the total catchment area from 0.08% to 0.20%. Whereas the quantity of water in the Keiskamma catchment fluctuated from 1994 to 2020. The results also demonstrated that, in the Mthatha catchment, the area occupied by water decreased from 14152 ha in 1994 to 4758 ha in 2020, which represents a -3.65% change in the overall composition of water bodies in response to LULC change. Although these results have demonstrated the robustness of earth observation data for water quantity mapping in the three catchments, we recommend that machine learning algorithms approaches and data cubes, should be used in future studies to handle huge geospatial and EO datasets and leverage faster, cost-effective ways to facilitate the analysis of remote sensing imagery at scale, by driving data straight into the hands of wider audiences and policymakers to support decision making.

2.2 Aim of the report

The aim of this chapter was to use spatial explicit earth observation techniques and *in-situ* based assessments to determine the impacts of land use and land cover changes on water quality and quantity in the Letaba, Mthatha and Keiskamma river catchments. This report is a follow-up to the earlier WRC report that focussed on “Land Use and Land Cover Change characterization in three catchments in South Africa”.

LULCC are among the principal environmental drivers triggering land, and water quality and quantity degradation. Specifically, anthropogenic activities, such as agriculture, forestry, industrialisation, mining, and urbanisation often lead to land use change, which increases effluent discharge into open water bodies (Masocha et al., 2019; Dube et al., 2020). These activities also tend to increase runoff, especially from paved surfaces in urban areas and poorly managed croplands, leading to increased transport of pollutants into open water bodies affecting water quality. The quality of water in major rivers, particularly in the selected catchments in Limpopo and some parts of the Eastern Cape provinces, show high degrees of pollution, particularly from both point and non-point sources. Protection of surface water resources from pollution and contamination has therefore since become a global priority for two main reasons. One of the key obstacles to sustainable management of surface water resources in South Africa is the scarcity of accurate spatial explicit information on water quality and quantity as well as levels of concentrations, especially at catchment or national scales. Previous work on water quality has been limited to few studies often targeting small-scattered sites (Dube et al., 2020). Catchment scale information on the status of water quality and quantity is therefore imperative if this resource is to be sustainably managed. Thus, assessing the effects of Land use and land cover on water quantity and quality at the catchment scale in the Letaba, Keiskamma and Mthatha basins is paramount. Of late, the three selected catchments have experienced rapid development, which oversaw massive land use and land cover changes (Siyongwana, 2005; Thamaga and Dube, 2018; Nyamugama, and Kakembo, 2015). For this particular project, in-situ physiochemical parameters were measured in three river sections, that is, the lower, middle and upper reaches of the Letaba, Mthatha and Keiskamma river catchments. In addition, water samples were collected for nutrient and heavy metal analyses. However, this report will focus mainly on the physiochemical parameters. The nutrient and heavy metal loads will be incorporated into the final report.

2.3 Study area description

2.3.1 Letaba River Catchment

The Letaba River catchment is located between longitudes 30°0′ and 31°40′ East and latitudes 23°30′ and 24°0′ South, in the Mopani District of Limpopo Province, South Africa (Figure 1.1). The Letaba River catchment has a surface area of 67,000 km^2. The Letaba River flows eastwards across the Kruger National Park (KNP), where it joins the Olifants River a short distance upstream of the Mozambique border. The river catchment basin comprises six large dams from upstream to downstream including Ebenezer Dam, Tzaneen Dam, Modjaji Dam (in the Molototsi River), Hudson Ntsanwisi Dam (in the Nsama River), Middle Letaba Dam (in the Middle Letaba River) and Engelhard Dam. These dams are the major sources of water supply to the towns of Tzaneen, Polokwane Phalaborwa, and villages scattered around the catchment and to agricultural and mining water users. Some of the major tributaries to the left include; the Nharhweni River, Ngwenyeni River, Klein Letaba River, Molototsi River, and Nsama River. Whereas, on the right lies river tributaries such as the Groot Letaba River, Nwanedzi River, and Makhadzi River.

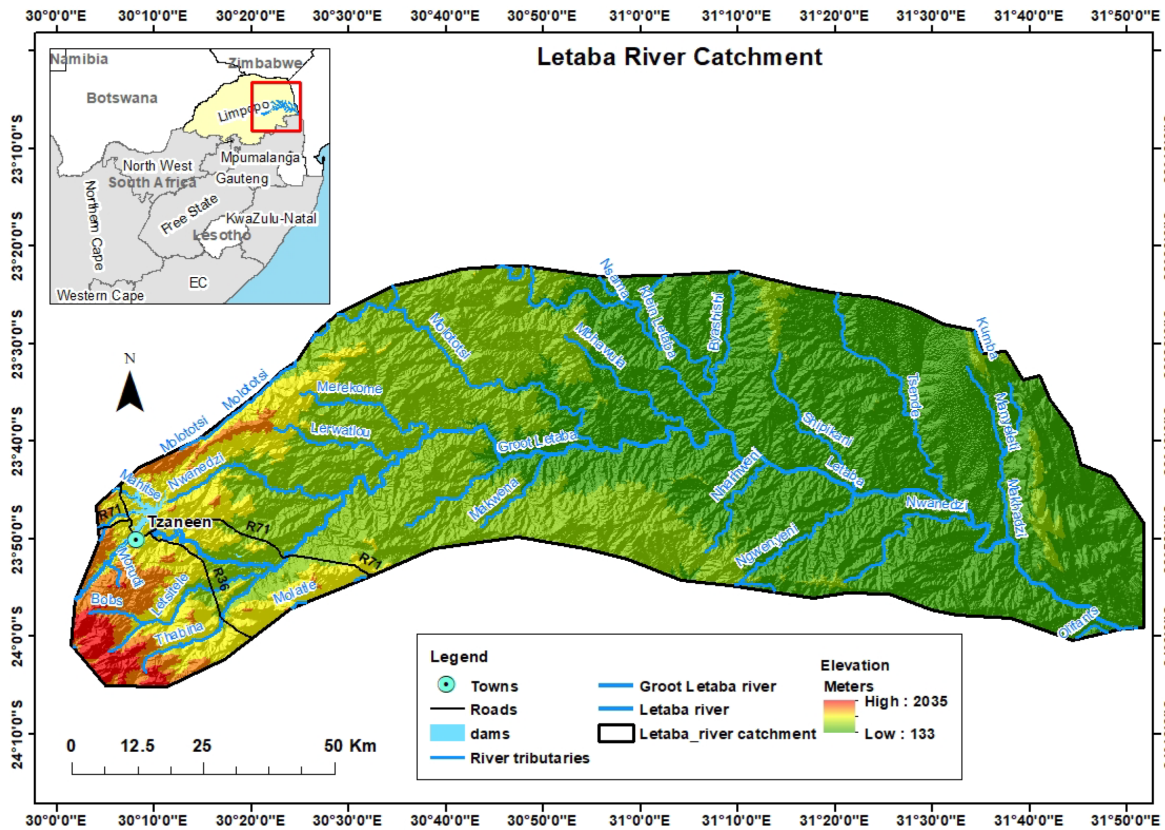


Figure 2.1: Letaba River catchment

Letaba River changed from a perennial to a non-perennial river in the 1950s, mainly due to the construction of the storage dams and subsequent water use for drinking and irrigation (Querner et al., 2016). The mean annual runoff (MAR) of the Letaba catchment is 574 mln m^3 (range from 100 to 2 700 mln m^3) (DWAF 2003). Variation in terms of topography (altitude and relief) from east to west around the Letaba River gives rise to different climatic characteristics. For instance, rainfall around the mountainous region of the Letaba River has a yearly average of approximately 2000 mm, while the Lowveld region on the eastern side has a yearly average of 400 mm (State of Rivers Report, 2001). The area is characterised by summer rainfall and normally evaporation rates steadily increase from the west (1400 mm/a) to the east (1900 mm/a) (State of Rivers Report, 2001). The average annual temperature ranges from 21°C in the upper catchments, to 25°C in the Lowveld (State of Rivers Report, 2001). Frost rarely occurs in these areas. The highest peaks have an elevation of more than 2 000 m, whereas the lowest point has an elevation of 133 m above mean sea level.

2.3.2 Keiskamma River Catchment

The Keiskamma is one of the largest catchments in the semi-arid region of the Eastern Cape Province of South Africa, covering an area of 2 745 km² which forms approximately 35% of the former Ciskei region (Hill, 1991) (Figure 1.2).

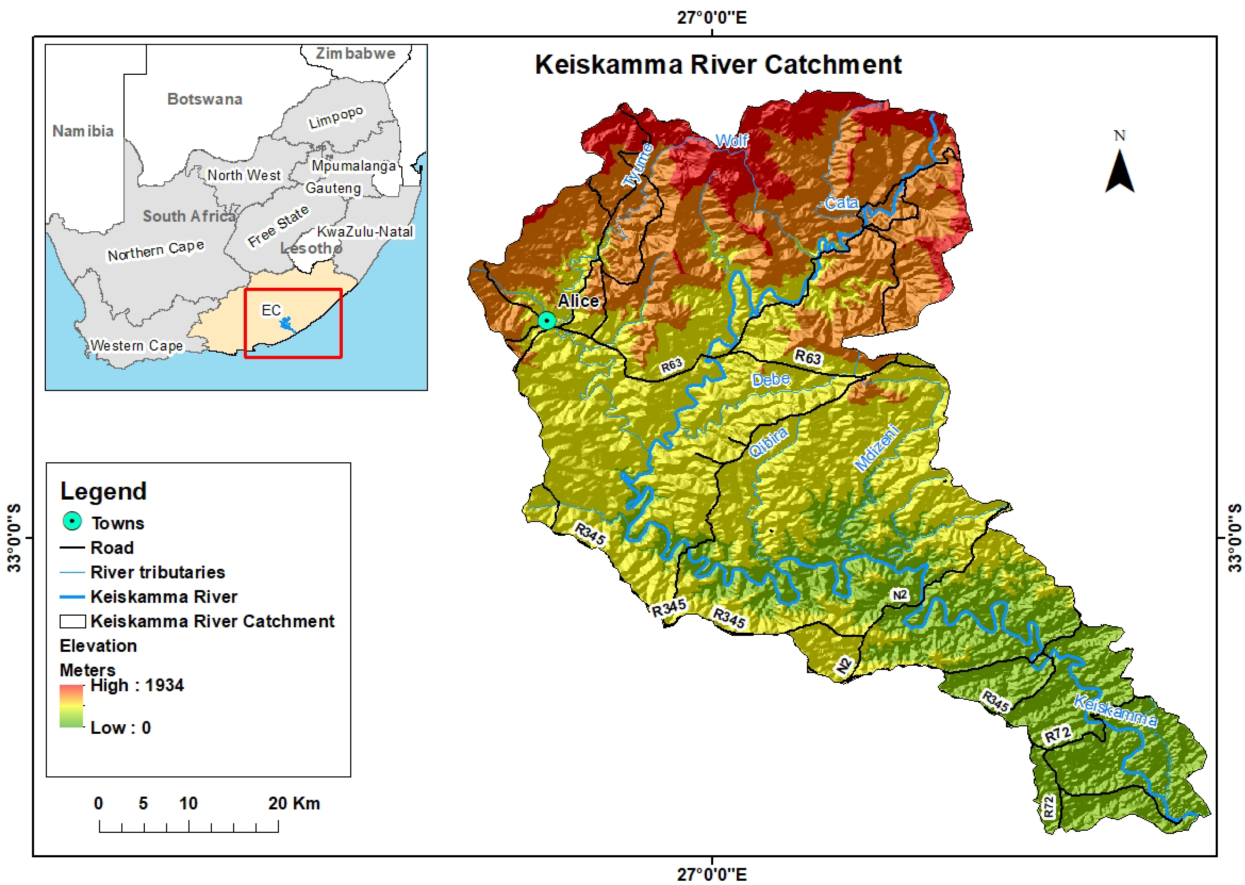


Figure 2.2: Keiskamma River catchment

The Keiskamma river is the main river in the catchment with headwaters situated in the Amatole Mountains above Keiskammahoek town and flows eastwards for 263 km and drains into the Indian Ocean at the resort town of Hamburg (33°17´S 27°29´E). The main tributaries of the

Keiskamma River are Tyume, Chalumna and Gulu, with the Tyume headwaters in Hogsback (DWAF, 2004).

Climatic variations in the catchment are highly associated with elevation and proximity to the sea. The escarpment zone, which comprises mountain forests and pine plantations receive annual rainfall amounts of about approximately 1 900 mm while the semi-arid coastal plateau receives 400-600 mm, with most of the rainfall received occurring in summer months (Mhangara, 2011). The mean annual rainfall is spatially distributed according to the topographic zonation of the catchment.

The summer months receive the most rainfall while June and July winter months are the driest (Mhangara, Kakembo, & Lim, 2012). Large areas in the escarpment zone are protected and its land cover conditions can be described as pristine. Average annual temperatures are 11°C for the escarpment zone and 18°C for the coastal plateau (Mhangara, 2011). Temperatures can rise and fall to 38°C and -2°C in summer and winter respectively (DWAF, 2004). Summer temperatures regularly exceed 40ºC; cold temperatures are experienced during the winter months with occasional snowfalls in areas between the Amatole mountain range and Keiskammahoek to the Hogsback area. This contrasts with coastal areas where temperature variations are less pronounced (Mhangara, 2011).

The Keiskamma River Catchment exhibits the climatic vulnerability of various catchments on the Eastern Cape coast (Mhangara, 2011). The catchment is explicitly categorised into three topographic zones, that is escarpment, plateau and coastal zones (DWAF, 2004). The escarpment zone receives higher rainfall and mostly contains comprises protected mountain forests, whereas the plateau zone encompasses communal settlements where land degradation in the form of soil erosion, vegetation invasions and reduction, are among the key environmental problems. These problems have been aggravated by increased and uncontrolled land-use practices, which have had resulting in a major impact on the water quantity and quality of the Keiskamma River. It is necessary to investigate the impacts of these land use and land cover changes within the catchment to establish implications on water quality and quantity in key water resources in the catchment. The findings could then be extrapolated to other catchments with similar vulnerability to formulate suitable environmental change and adaptation strategies in the catchments of South Africa. Mthatha River Catchment.

1.1 Mthatha River Catchment

Mthatha River Catchment lies between latitudes 31°36'29.19"S and Longitudes 28°49'30.05"E (Figure 2.3). The catchment is located in the T20 tertiary catchment, which lies within the Mzimvubu to Keiskamma Water Management Area (WMA 12) (proposed new WMA is Mzimvubu to Tsitsikamma WMA 7 – Government Gazette 35517, Notice No. 547, 20 July 2012). Mthatha river catchment is situated in King Sabata Dalindyebo and Nyandeni Local Municipalities of the O.R Tambo District Municipality in the Eastern Cape Province. The perennial Mthatha River originates in the Drakensberg at 1400 m elevation, it is approximately 250 km long and 50 km wide and covers an area of about 5 520 km^2. Mthatha River Catchment consists of the main river (Mthatha River) which is approximately 250 km long and has two large tributaries, winds its way to the sea north of Coffee Bay.

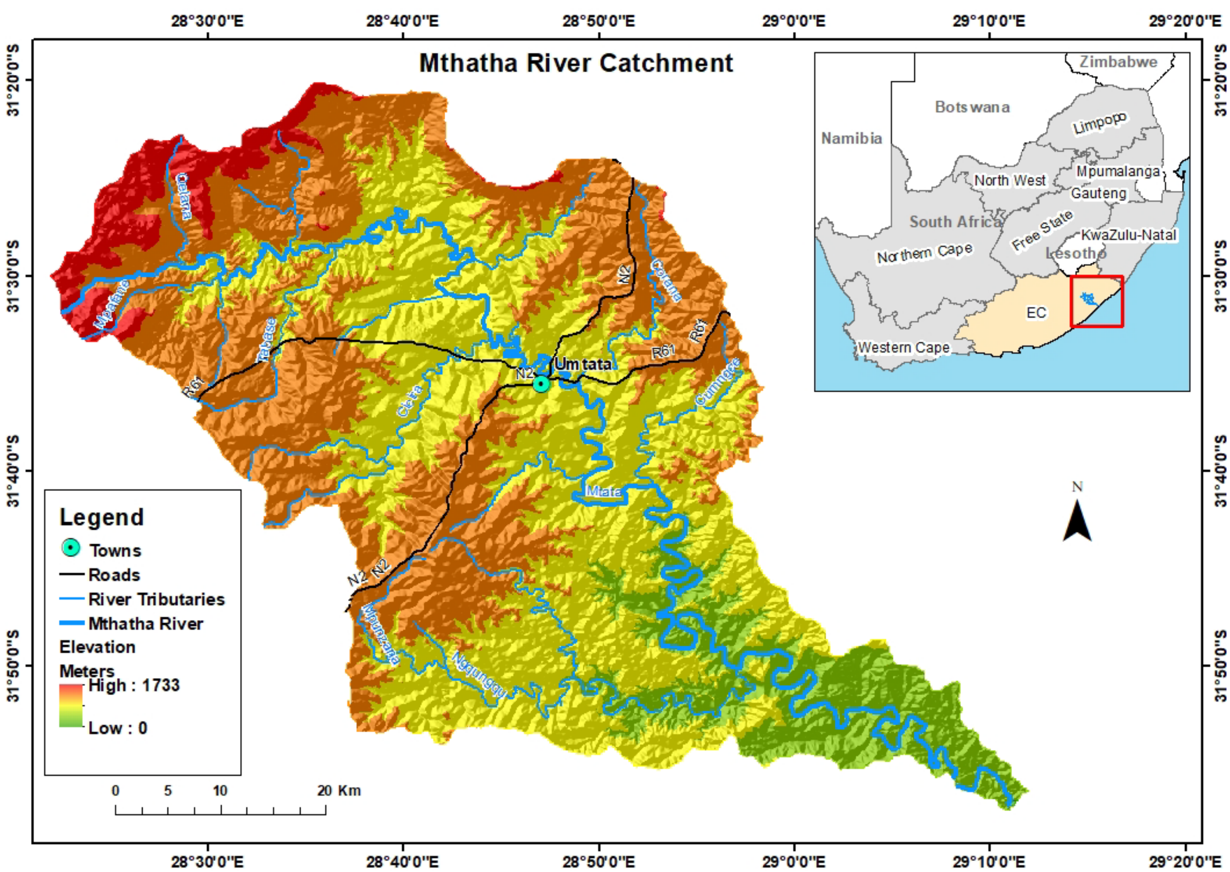


Figure 2.3: Mthatha River Catchment.

The catchment comprises predominantly mountainous and valley tops. The vegetation is largely grassland with some natural and commercial plantations. The topography of the King Sabata Dalindyebo and Nyandeni Municipalities is incised with large river valleys and floodplains that run on a northwest-southeast axis. The inland areas, which typify the study site, could be described as undulating to hilly, with moderate to steep slopes. The landscape is interspersed with grassland areas and patches of forest, with the river valleys covered by a thicket. The upper catchment area includes the Mthatha River headwaters and the Qelana tributary. The uppermost regions of the headwaters are still in a natural state as they are not accessible to humans and cattle. The upper reaches are mainly covered by commercial forest plantations. Commercial water use is dominated by forestry-related industries (Langeni and KwaBhaca sawmills), followed by the industrial, urban and rural sectors. The agricultural sector is poorly developed within the catchment with scattered subsistence small-scale irrigation throughout the catchment and particularly in the middle and lower reaches of the catchment using water pumped directly from the rivers using pumps (DWAF, 2008). The Mthatha town is located in the middle reaches of the catchment and is predominately covered by built-up areas, factories and industries. Informal settlements naturally cluster near employment opportunities, such as the timber mills in Ugie and Mthatha towns. Patches of grassland are open for grazing. Subsistence farming and forestry are the main land use in the catchment. A few natural areas exist, mainly around the steep valleys towards the coast (DWAF, 2008).

Mthatha Dam is the major water storage reservoir in the Mthatha catchment of the Mthatha River. This dam has a catchment area of 886 km^2 and can store up to 254 million m^3 of water while yielding about 14,5 million m^3 of water a year. Mthatha Dam supplies Mthatha town and the surrounding areas with domestic water and acts as balancing water storage, supplying the small dams at First and Second Falls downstream of Mthatha town (DWAF, 2008). Major land-use types in the Mthatha river catchment area are water bodies, forest plantations, built-up areas, cultivated lands, natural forests, and grasslands.

2.4 Materials and Methods

2.4.1 Field data collection

Fieldwork was conducted in each catchment from 1 October to December 25, 2020. During the first field visit, data on the dominant and different land cover was recorded using the Garmin GPS. The data were used in training and validating the land use and land cover results. Land use and land cover change results were further assessed to determine the magnitude of change within the three selected catchments. Visual assessments and statistical analysis demonstrated that in all three catchments, significant LULCC were incurred in the upper, mid, and lower parts of the catchments. As such, water quality sampling was conducted following the observed trends. Samples were thus collected in the upper, mid and lower parts of the main rivers within three catchments. Water samples were thus collected in the upper, mid and lower parts of the main rivers within the three catchments in February 2021. During each survey, water temperature (°C), pH, dissolved oxygen (mg/L), electric conductivity (EC; µS/cm), total dissolved solids (TDS;) and salinity (ppt) were measured in-situ at each site using a handheld YSI Model 554 Data logger multiprobe. During water quality sampling, forty-eight samples were collected in the Letaba catchment. Specifically, 16 samples each were collected from the upper reaches, the middle reaches, and the lower reaches of the catchments. GPS coordinates were also taken at each sampling position. Similarly, in the Mthatha catchment, forty-five water samples were collected in the upper (15), middle (15) and lower (15) reaches of the river. However, in the Keiskamma catchment, only a total of 9 samples were collected; three (3) in the upper reaches, 3 in the middle reaches and 3 in the lower reaches using a handheld multi-parameter probe (HI9829, Hanna instruments) which has an inbuilt GPS. Afterwards water samples were collected at each sampling location corresponding to *in-situ* water quality measurements in the upper, middle, and lower streams of each catchment. The surface water samples were collected using a bucket tied to a rope at a depth of 10 cm, then the water was poured into polyethene sampling bottles (250 mL) washed with de-ionized water as described by Moyo and Rapatsa (2019). The samples were then stored in cooler boxes with ice then transported to the laboratory for analysis. At the laboratory, the samples were filtered with a 0.45 µm membrane filter and 10 mL of 65% nitric acid was added to preserve them during storage in refrigerators below 4˚C before analyses. The samples were analysed at the WaterLab in Pretoria for heavy metals and nutrient load (nitrates, sodium adsorption ratio, pH, total dissolved salts, cations, sulphates, carbonates, turbidity, etc.).

2.4.2 Statistical analyses of physiochemical data

The mean and standard deviation of the respective water chemistry and nutrient concentrations were calculated. An analysis of variance (ANOVA) was performed to determine whether there were spatial variations in the water chemistry and nutrients using Statistica (Version 10, 2007).

2.4.3 Satellite derived Land Use and Land Cover Change Mapping and Impacts on water quality and quantity

To determine and assess the impacts of land use and land cover on water quality, cloud free Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 OLI images were first used to map historical and current land use and cover types from the three selected river catchments, i.e. Letaba, Mthatha, and Keiskamma. Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 OLI were used because some satellite images were not available for some of the periods. Detailed information on the three satellite sensors is provided in Tables 2.1 and 2.2. Prior to LULC change mapping, we georeferenced all the images using ground-based control points collected during the field reconnaissance period that spanned from the 1st of October to the 25th of December 2020. The acquired satellite images were classified, using the commonly used maximum likelihood classification (MLC) algorithm. A detailed description of the land use and land cover-mapping framework is provided in Chapter 1. Image classification for the three selected catchments was achieved with an average classification accuracy of 72%. To determine if the LULC changes could have occurred within the three selected catchments, change detection was undertaken. Firstly, the area covered by each class for each year was computed, using spatial analyst tools in a GIS environment. This information was then used to determine the rate changes over the years. The same data was further analysed to determine the trends in the observed changes. However, in determining water quantity, more emphasis was placed on the water class and associated changes over the years.

Table 2.1: Summary detail of the satellite datasets used for LULC mapping.

Catchment	Satellite data	Acquisition date	Landsat product	Path/Row
Mthatha	Landsat 7 ETM+	09/10/2000	LE07_L1TP_169082	169/082
	Landsat 7 ETM+	06/01/2010	LE07_L1TP_169082	169/082
	Landsat 8 OLI	04/09/2019	LC08_L1TP_169082	169/082
Keiskamma	Landsat 7 ETM+	19/12/2000	LE07_L1TP_170083	170/083
	Landsat 7 ETM+	25/08/2010	LE07_L1TP_170083	170/083
	Landsat 7 ETM+	10/08/2019	LC08_L1TP_170083	170/083
Letaba	Landsat 5 TM	13/12/1994	LT05_L1TP_168076	168/076
	Landsat 5 TM	13/12/1994	LT05_L1TP_168077	168/077
	Landsat 5 TM	20/12/1994	LT05_L1TP_169076	169/076
	Landsat 5 TM	20/12/1994	LT05_L1TP_169077	169/077
	Landsat 5 TM	20/07/2005	LT05_L1TP_168076	168/076

	Landsat 5 TM	20/07/2005	LT05_L1TP_168077	168/077
	Landsat 5 TM	16/11/2005	LT05_L1TP_169076	169/076
	Landsat 5 TM	13/09/2005	LT05_L1TP_169077	169/077
	Landsat 8 OLI	15/09/2020	LC08_L1TP_168076	168/076
	Landsat 8 OLI	13/09/2020	LC08_L1TP_168077	168/077
	Landsat 8 OLI	11/12/2020	LC08_L1TP_168076	168/076
	Landsat 8 OLI	11/12/2020	LC08_L1TP_169077	169/077

2.4.4 Water Quality Assessment and Monitoring from the Three Selected Catchments

Following the observed changes in land use and land cover within the three catchments, we subdivided the catchments into three distinct categories (Figure 2.4). This informed the sampling framework to be adopted. Firstly, we statistically compared the levels of water quality concentrations across the three categories to determine the catchment or river sections that were more polluted.

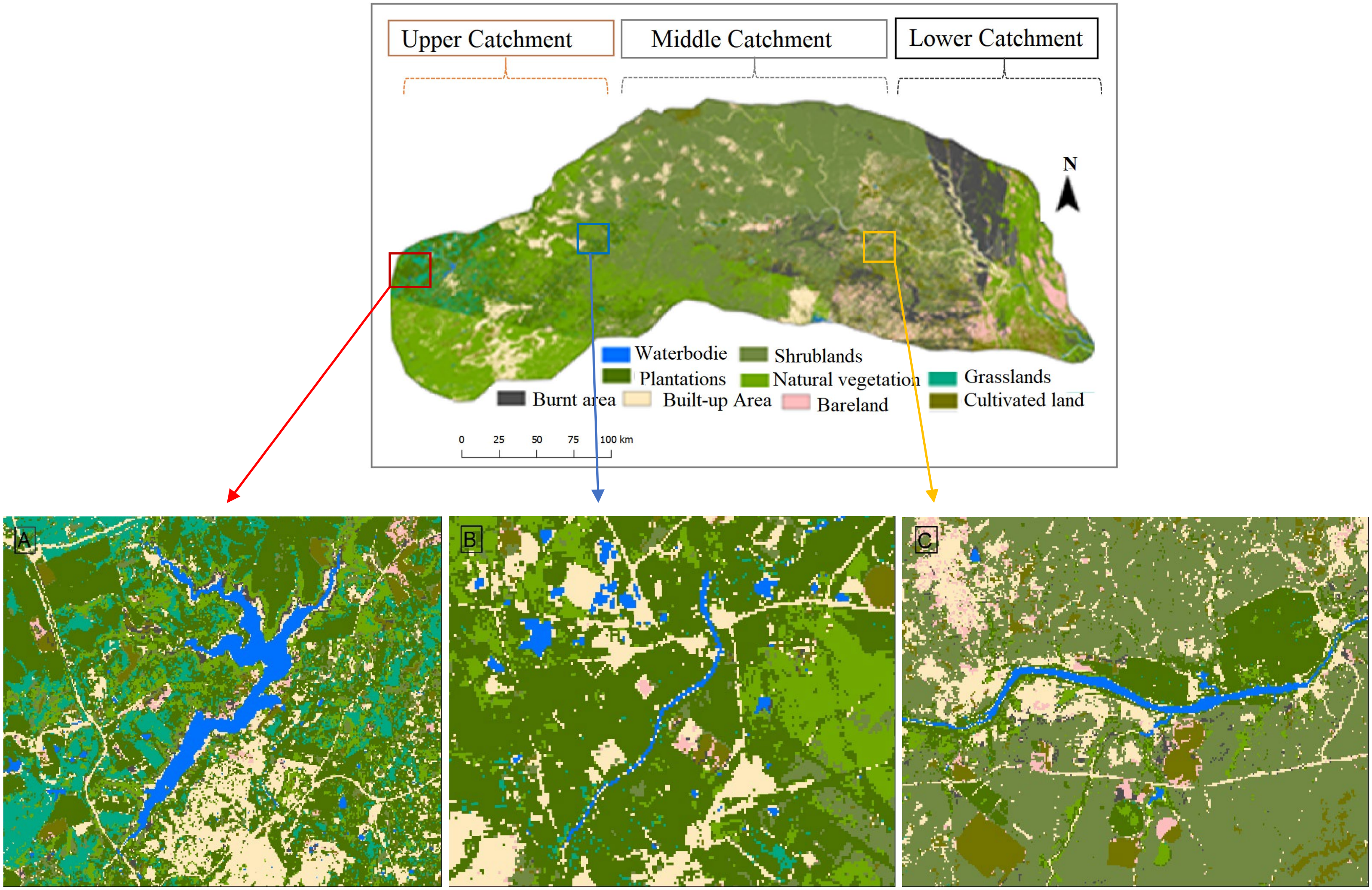


Figure 2.4: Satellite-derived Land cover map for Letaba catchment for the year 2020. (a) indicates the sampled upper catchment section, (b) middle catchment sampled area and (c) Lower catchment sampled locations

2.4.5 Satellite Data Acquisition and Modelling Water Quality

To model water quality parameters across the three selected river catchments (Letaba, Keiskamma, and Mthatha) medium resolution (10 m) datasets such as Sentinel 2 MSI satellite images corresponding to the month (e.g. February 2021) of fieldwork were acquired freely from USGS (United State Geological Survey) and ESA (European Space Agency) online catalogues respectively. Sentinel is an ESA, high-resolution multispectral imaging, polar-orbiting satellite mission, which image data types designed for seven years lifetime. The full Sentinel-1, 2, and 3 missions include twin satellites in the same orbit, and carry a push-broom Multi-Spectral Instrument (MSI) payload with the aim of land cover change detection, agricultural applications, coastal zone, inland water and Glacier monitoring. The sensor is characterised by a swath-width of 290 km Field of View (FOV), Multispectral data with 13 bands (443-2190 nm) from VNIR to SWIR. Furthermore, the sensor has spatial resolution at 10 m (four visible and near-infrared bands), 20 m (six red-edge and shortwave infrared bands) and 60 m (three atmospheric correction bands), 5 days' revisit, and 12-bit radiometric resolution. From five Sentinel-2 product types, Level-0, and Level-1A products are not available, and Level-1B, Level-1C, and Level-2A products are available for users. These unique sensing characteristics allow for catchment-scale water quality and quantity monitoring and assessment over time with reasonable accuracy – a previously challenging task with broadband multispectral; sensors together with non-routine in-situ measurements (Soomets et al., 2020). Sentinel-2 Toolbox version 6.0.0 in Sentinel Application Platform (SNAP) on Windows 10 (64 bit) and QGIS were used to process the images. Atmospheric corrections were done, using the dark object subtraction (DOS1) model (Sepuru and Dube, 2018). The images were then projected to WGS 84 datum.

2.4.6 Water Quality Spatial Data Analysis

A point map of the water sampling areas was created using field data and GPS readings. The points were superimposed on the Sentinel 2 MSI image, and then band values or image spectra were extracted to points using ArcGIS 10.3 software. The extracted image spectra were then averaged for each river catchment, and saved on a Microsoft Excel Spreadsheet for analysis. The commonly used water indices such as the Normalised Difference Water index (MacFeeters, 1995); The Normalised Difference Turbidity Index (NDTI) (Lacaux et al., 1986) and the Modified Normalised Difference Water Index (MNDWI) (Xu, 2006) were calculated in this study to map water quality and water quantity. Water indices have proven to accurately map water bodies, for instance, MNDWI uses green and SWIR bands for the enhancement of open water features

(Xu, 2006). It also diminishes built-up area features that are often correlated with open water in other indices (Xu, 2006). Table 2.2 shows the list of other water indices that were tested to identify the best index for estimating water quality with Sentinel 2MSI.z

Table 2.2: Summary detail of spectral water indices used for water quality mapping.

Index	Formula	Reference
NDWI	NDWI = (Bgreen - BNIR)/(Bgreen + BNIR)	MacFeeters (1995)
mNDWI	mNDWI = (Bgreen - BSWIR-1)/(Bgreen + BSWIR-1	Xu (2006)
NDWI plus VI	EVI = 2.5 * (BNIR-Bred)/(BNIR + 6.0 * Bred - 7.5 * Bblue+1)	Menarguez (2015)
mNDWI plus VI	NDVI = (BNIR - Bred)/(BNIR + Bred)	Menarguez (2015)
LSWI plus VI	LSWI = (BNIR - BSWIR-1)/(BNIR + BSWIR-1)	Menarguez (2015)
LSWI plus VI	AWEIsh=Bblue+2.5 *Bgreen - 1.5 *(BNIR+BSWIR-1) - 0.25 * BSWIR-2	Feyisa et al. (2014)
AWEInsh	AWEInsh = 4 * (Bgreen-BSWIR-1) - (0.25 * BNIR-2 + 2.75 * BSWIR-1)	Feyisa et al. (2014
GNDVI	GNDVI = (NIR - Green)/(NIR + Green)	Gitelson et al. (1996)
NDTI	NDTI = (Red - Green) / (Red + Green)	(Lacaux et al.,1986)

Spectral indices from Table 2.2 were selected because normally water bodies have low reflectance or high absorption in the optical regions of the electromagnetic spectrum when compared to other materials of the earth’s surface, therefore this will help to accurately discriminate water from data (Masocha et al., 2018; Zhou et al. 2017).

In order to determine the relationship between spectral bands and water indices and water quality parameters, Pearson’s correlation coefficient (r) was used. The correlation coefficient (r) was analysed at α = 0.05 measuring the strength of the linear relationship between selected water quality parameters (Dissolved oxygen, Electrical conductivity, Salinity, Total Dissolved Solids, pH and Water temperature), individual bands and indices. Furthermore, stepwise multiple linear regression (R^2) was used to estimate water quality using remote sensing data and in-situ field measurements. The subsequent linear relationship was assumed as follows:

$$Y = \beta_0 + \beta_{1.} * X_1 + \varepsilon \qquad \text{Eq. 1}$$

Where Y is the in-situ water quality parameter, X_1 is variable vectors corresponding to Sentinel 2 MSI data derived spectral and water indices, β_0 and β_1 are the coefficients that characterise the model and the ε is the additive bias (Corona et al., 1998). The novelty behind performing the regression analyses is to predict the regression potentials between the actual and the remotely sensed estimated water quality parameters. To quantitatively evaluate the results of the models, the coefficient of determination (R^2) was calculated as:

$$R^2 = 1 - \left(\frac{SS_{res}}{SS_{tot}} \right) \qquad \text{Eq. 2}$$

where SS_{res} is the residual sum of squares and SS_{tot} is the total sum of squares (Sagan et al., 2020; Draper and Smith, 1981). Then the actual parameters were plotted against the estimated parameters and root mean square error (RMSE) values are used to obtain the best fit. RMSE is obtained as follows;

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (p_i - O_i)^2}{n}} \qquad \text{Eq. 3}$$

Where *P* is the predicted value; *O* is the observed value. Mean absolute percentage error (MAPE) is the average of absolute errors divided by actual observation values (Draper and Smith, 1981). MAPE was also calculated to evaluate model performance. MAPE is calculated as:

$$MAPE = \frac{\sum_{i-1}^{n} \frac{| y_i - y_i |}{y}}{n} x100$$

2.4.6.1 Water Quality Model Validation

A complete Leave-One-Out Cross-Validation (LOOCV) method was used to calculate the root means square error (RMSE) of the models used to map water quality in the study (Ji et al., 2012). LOOCV was selected over other methods of validation because there were no statistical significances to split the in-situ water samples data for validation since the samples collected were few (n = 48) across all three catchments. The cross-validation has a single hyperparameter “k” that controls the number of subsets that a dataset is split into. Once split, each subset is given the opportunity to be used as a test set while all other subsets together are used as a training dataset (Ji et al., 2012).

2.4.6.2 Mapping water quality

An algorithm generated through a regression method was used to make a spatial prediction for water quality parameters. The algorithm ($Y = \beta_0 + \beta_{1.} * X_1 + \varepsilon$) was applied to the Sentinel 2 MSI images of Letaba, Keiskamma and Mthatha river catchments using a raster calculator tool in ArcGIS environment to get a spatial distribution map of water quality parameters (Dube et al., 2015). Water quantity information was extracted from Land cover/Land use data generated in Chapter 1 and presented in the form of tables.

2.5 Results

2.5.1 Physicochemical parameters

The physicochemical parameters such as dissolved oxygen (DO), pH, temperature total dissolved solids (TDS) and electrical conductivity (EC) of Letaba, Mthatha and Keiskamma river catchments are presented in Table 3 and Figures 2.4, 2.6, and 2.7. The results indicate that high concentrations of the six parameters considered for this project were dominantly found in the lower parts of the catchments as compared to the mid and lower parts of the catchment.

Temperatures in all three catchments ranged from 21.36 ˚C to 26.57˚C. Highly significant differences ($p < 0.000$) among the three reaches (sections) of the rivers were observed in all the catchments. It was observed that the temperatures were significantly high in the lower reaches of the rivers (Table 2.3). In Letaba and Keiskamma catchments the lowest temperature was observed in the upper reaches (Figures 2.5 and 2.6) while for Mthatha no differences were observed between the middle and upper (Figure 2.3). River water temperature affects photosynthetic activity, diffusion rate or gases, and the amount of oxygen that can be dissolved, among others. More gas can be dissolved in cold water than in warm (Kale, 2016).

Dissolved oxygen (DO) was found to highly vary in the Mthatha and Letaba catchments ($p < 0.000$) (Figures 2.1 and 2.3) but did not show any difference in the Keiskamma catchment (Figure 2.2) ($p > 0.05$). In the Letaba catchment, DO ranged from 1.66 mg/L in the upper to

4.04 mg/L in the lower reaches. In the Mthatha catchment, it ranged from 7.98 to 8.47 mg/L while in the Keiskamma it was between 7.87 and 7.94 mg/L (Table 2.2). Dissolved oxygen is required by all forms of aquatic (Trivedi et al., 2009) and is supplied through several methods such as direct diffusion of oxygen from the atmosphere, wind and wave action; and photosynthesis (Kale, 2016). According to the Department of Water Affairs and Forestry of South Africa (DWAF) 1996, DO in freshwater should be around 10 mg/L. Thus all three catchments had relatively lower values of DO. The low DO values observed may be attributable to the discharge from the catchments brought in by flooding during the research period, the rate of oxygen consumption by aquatic species, and the rapid rate of decomposition of organic waste during the summer months.

Variations of mean TDS and EC values were highly significant ($p < 0.001$) among the reaches across all three catchments (Table 2.3, Figure 2.5, 2.6 and 2.7). High levels of EC and TDS were recorded in the lower reaches of the rivers, which is an indication of high levels of electrolytes, and ions in the solution. This can be attributed to dissolved organic compounds and the influx of metals and salts from the catchment. The elevated TDS values recorded can also be due to the occurrence of phytoplankton blooms, which can account for the lower DO levels recorded. DO is used by many organisms in the water, and thus tends to change rapidly.

Throughout the study, alkaline conditions were recorded in the Letaba (pH 8.38-8.58) and Mthatha (pH 7.58-7.71) catchments (Table 2.3). However, no significant differences in pH were observed between the reaches in both catchments. In the Keiskamma catchment, acidic conditions were recorded with pH, ranging from 4.62 to 4.93. In addition, significant differences were observed between the reaches with upper reaches having significantly higher pH compared to the middle and lower reaches. The pH of water determines the solubility and biological availability of chemical constituents such as nutrients (phosphorus, nitrogen and carbon) and heavy metals (lead, copper, cadmium, etc.). Heavy metals tend to be more toxic at lower pH because they are more soluble (Kale, 2016). The finding of this study shows that heavy metal toxicity could be a problem in the Keiskamma catchment due to the acidic nature of the water in the river. Salinity levels were higher in the lower reaches compared to the upper and middle in all three catchments. No differences were observed between the middle and lower reaches.

Table 2.3: Physicochemical parameters of the Upper, Middle and Lower reaches of the Letaba, Mthatha and Keiskamma Rivers

		Parameter					
Site	**Reaches**	**DO**	**EC**	**TDS**	**SAL**	**PH**	**Temperature**
Letaba	Lower	4.04a	174.48a	109.44a	0.220a	8.58	25.46a
	Middle	3.90a	121.14b	84.37b	0.065b	8.46	24.11b
	Upper	1.66b	64.05c	41.23c	0.029b	8.38	21.53c
	p value	***0.0001***	***0.0001***	***0.0001***	***0.0002***	***0.170***	***0.0001***
Mthatha	Lower	7.98c	51.00a	Na	0.05a	7.62	24.48a
	Middle	8.47a	45.60b	Na	0.04a	7.71	22.77b
	Upper	8.31b	26.53c	Na	0.00b	7.58	23.53b
	p value	***0.0001***	***0.0001***		***0.0030***	***0.3777***	***0.0002***
Keiskamma	Lower	7.94	263.33a	131.67a	0.12a	4.75b	26.57a
	Middle	7.87	128.33c	64.33c	0.06b	4.62b	24.23b
	Upper	7.79	137.00b	68.67b	0.06b	4.93a	21.36c
	p value	***0.3341***	***0.0001***	***0.0000***	***0.0199***	***0.0010***	***0.0001***

Different letters in the same column indicate significant differences.

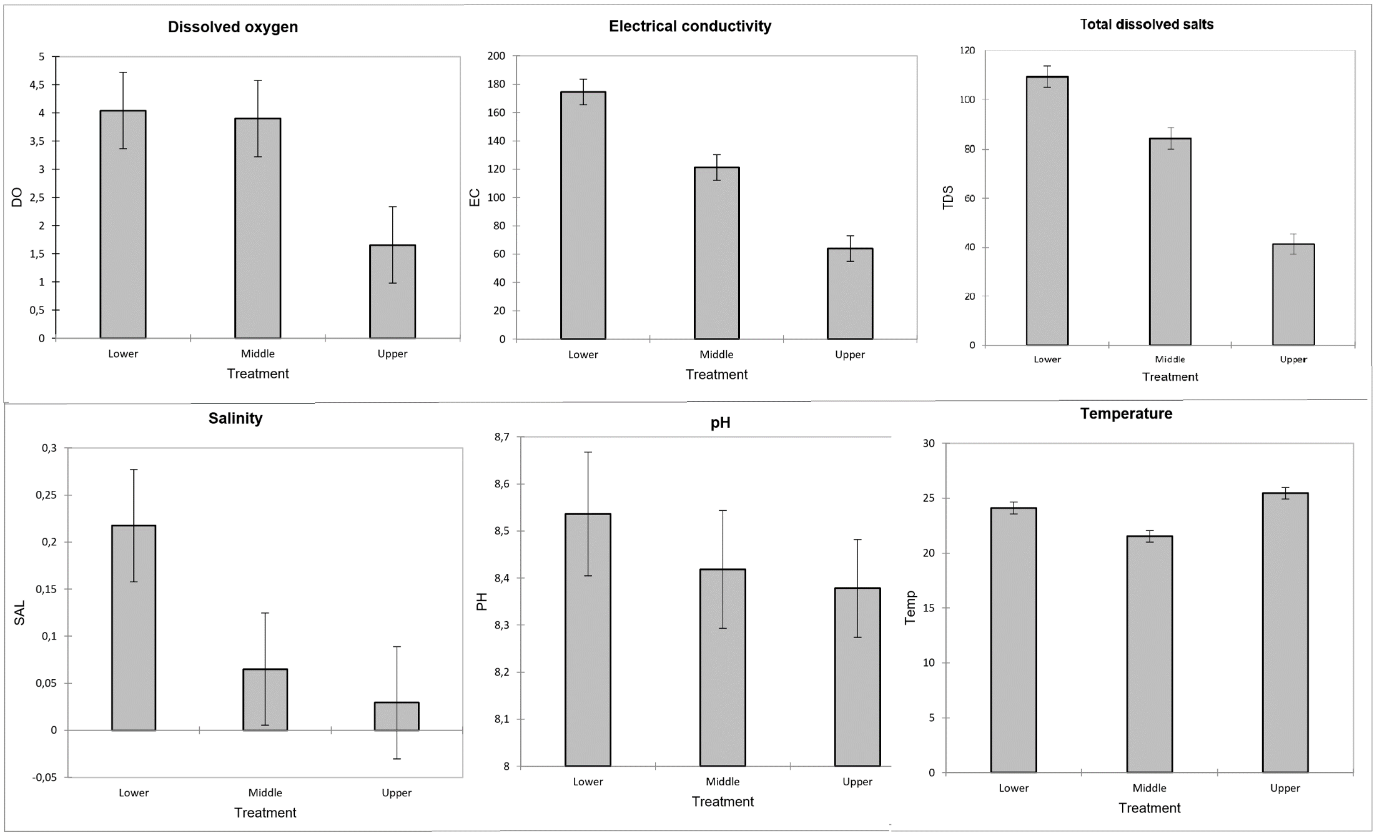


Figure 2.5: Physiochemical properties of the Letaba River

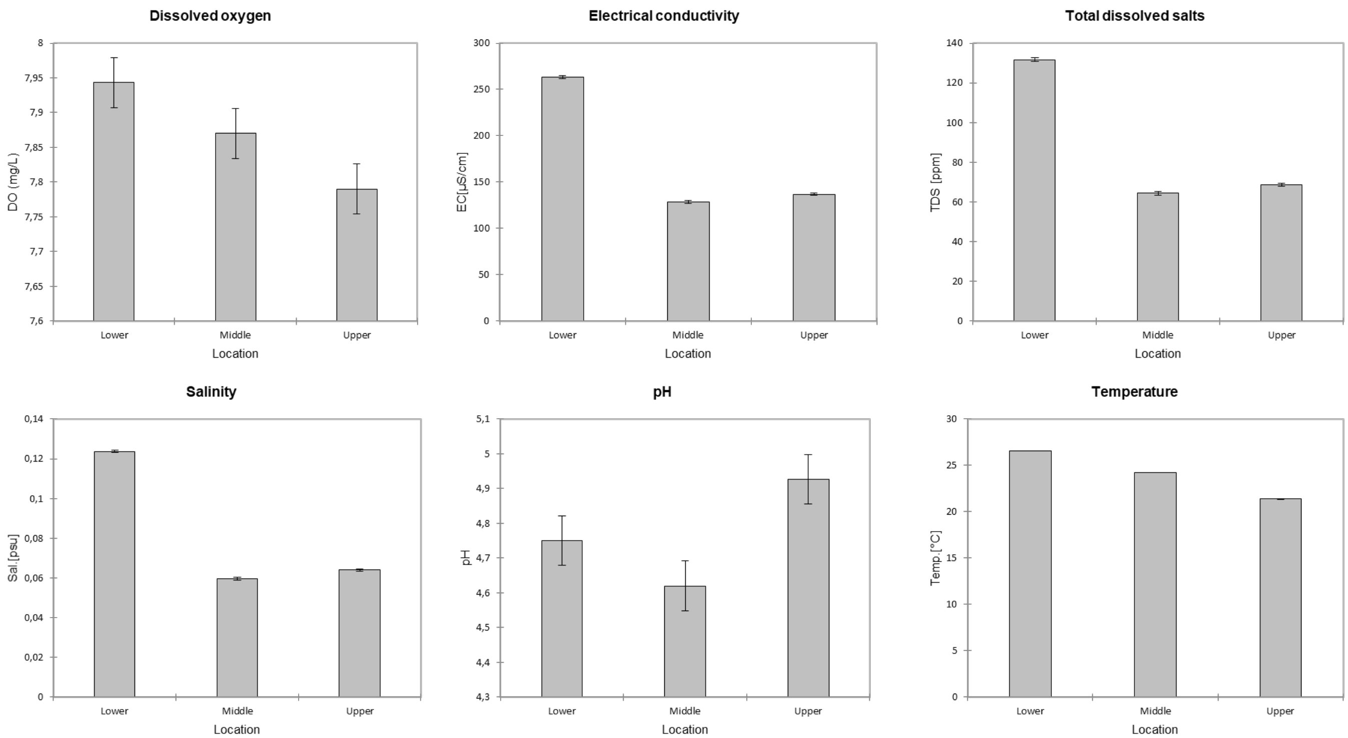


Figure 2.6: Physiochemical properties of the Keiskamma River

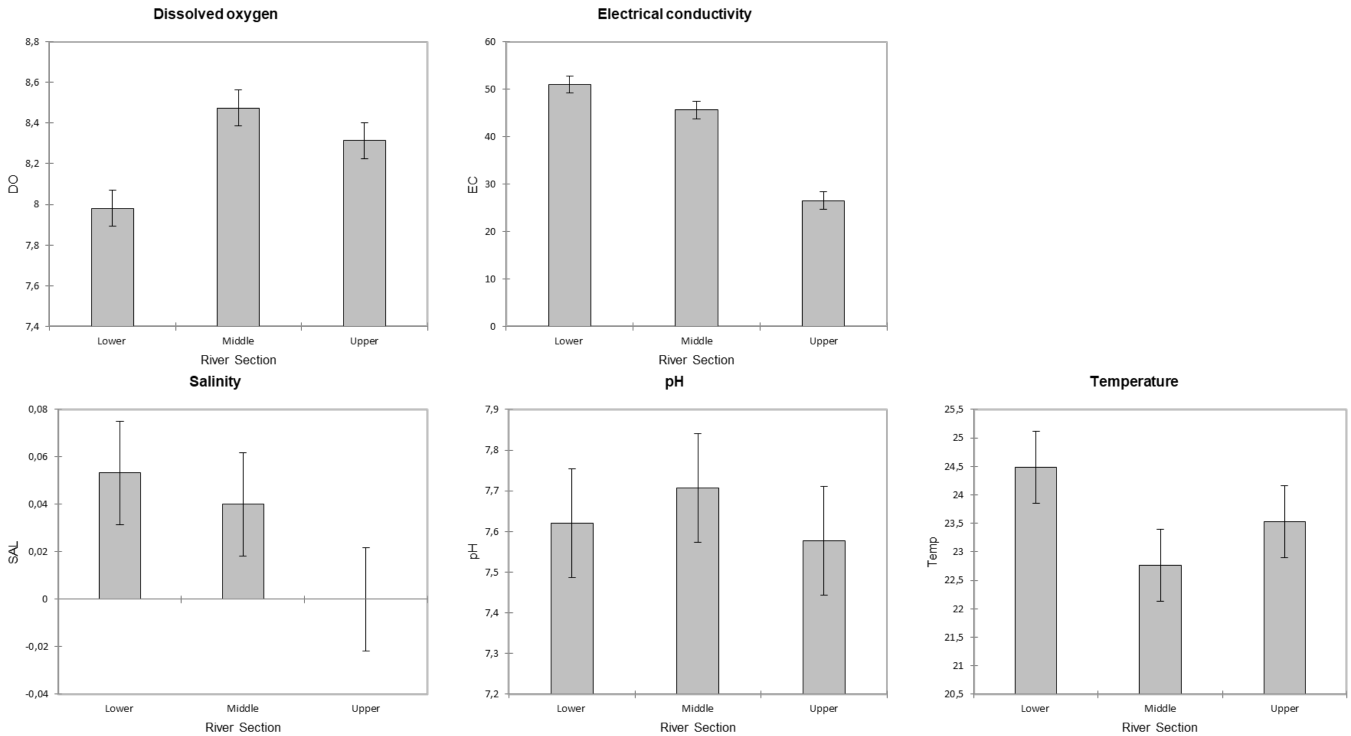


Figure 2.7: Physiochemical properties of the Mthatha River

2.5.2 The relationship between in-situ water quality parameters, bands and indices

The relationships between *in-situ* measurements and satellite derived spectral bands and indices were established (Table 2.4). The results indicate strong correlations between the bands mainly in the visible and red-edge region of the electromagnetic spectrum (2,3,4,5) and in-situ water quality parameters such as DO, EC, TDS, SAL and PH. For example, the results showed high correlations (α .05. However, the Near Infrared (NIR – 6, 7, 8, 8A) and Shortwave Infrared region (SWIR -11,12) showed very weak correlations with in-situ water quality parameters. Temperature portrayed very weak correlations when related to all water quality variables, with correlation coefficient (r) ranging from -0.15 to 0.26. Similarly, all indices tested in this study performed poorly when correlated with in-situ water quality parameters, except for Normalised Difference Turbidity Index (NDTI) which correlated with all field observed water quality parameters (-0.4 < r > 0.89).

Table 2.4: The correlation coefficient between water quality parameters, bands and indices for the Letaba river catchment.

Variables	DO	EC	TDS	SAL	PH	Temp
B02	**0,518**	**0,627**	**0,561**	**0,727**	**-0,450**	0,049
B03	**0,587**	**0,713**	**0,651**	**0,767**	**-0,484**	0,010
B04	**0,643**	**0,797**	**0,750**	**0,764**	**-0,502**	-0,073
B05	**0,565**	**0,684**	**0,632**	**0,684**	**-0,458**	0,022
B06	0,147	-0,020	-0,013	0,080	0,003	-0,094
B07	0,128	-0,057	-0,042	0,019	0,038	-0,121
B08	0,048	-0,012	-0,066	0,194	-0,088	0,229
B8A	0,056	-0,154	-0,134	-0,052	0,085	-0,118
B11	0,004	-0,168	-0,173	0,008	0,000	-0,002
B12	0,039	-0,116	-0,146	0,119	-0,114	0,104
NDWI	0,052	0,096	0,123	-0,011	0,000	-0,156
mNDWI	0,038	0,251	0,218	0,175	-0,082	0,154
NDWI plus VI	**-0,333**	**-0,478**	**-0,501**	-0,267	0,212	0,266
mNDWI plus VI	-0,177	-0,258	**-0,288**	-0,091	0,081	0,223
LSWI plus VI	0,128	**0,432**	**0,345**	**0,407**	-0,207	**0,400**
AWEIsh1	**0,350**	**0,543**	**0,533**	**0,391**	-0,264	-0,113
AWEInsh	0,232	**0,449**	**0,431**	**0,295**	-0,192	-0,004
GNDVI	-0,052	-0,096	-0,123	0,011	0,000	0,156
NDTI	**0,649**	**0,859**	**0,890**	**0,506**	**-0,411**	**-0,403**

Values in bold are different from 0 with a significance level alpha= 0.05

In-situ measurement values were also regressed against the different band combinations and indices (Table 2.5) successfully used in the literature for different sensors. The stepwise approach was used because it reduces the number of predictors, reducing the multicollinearity problem and it is one of the ways to resolve the overfitting (Hocking, 1976). Different band combinations and indices were modelled and evaluated to predict water quality, using R^2, MSE, RMSE, and MAPE. The results on Table 2.5 shows that dissolved oxygen (DO) was predicted using Sentinel 2 band 4 and Normalised Difference Turbidity Index, with coefficient determination (R^2) of 0,47 and RMSE of 1,28 mg/L. The DO model was also found to be highly significant at p<0.0015. Whereas, for the estimation of electrical conductivity (EC), band 4, AWEInsh and NDTI were used since the other variables were eliminated by the stepwise approach. The EC model showed a highly significant level at alpha=0,05, with p-value yielding <0,0001, with R^2 of 0.84 and RMSE of 12,09 S/m. The total dissolved oxygen (DO) model yielded the highest coefficient of determination (R^2=0.86) when compared to other models evaluated in this study. However, only band 7, AWEInsh and NDTI were used to model DO and achieved RMSE of 11,62 mg/L with a p-value of <0,0001. The Sentinel 2 MSI, Green (Band 3) and Red (Band 4) bands were found to be useful in predicting water salinity (SAL) and PH, respectively in the study. With SAL model significantly yielded a moderate R^2 of 0.59, with an RMSE of 0.09. The results also found that the pH model performed poorly when compared to other models tested in the study, yielding the lowest R^2 of 0.25, and RMSE of 3.14, p<0.000. Another, model which performed moderately is the water temperature model and it managed to achieve the R^2 of 0.66 using the combination of the bands found in the red edge and near-infrared region (band 5 and 8), as well as mNDWI plus, LSWI plus VI and NDTI. The model was significant at alpha=0,05, with a p-value yielding <0,0001 and RMSE of 1.19°C. All the optimum models were used to create water quality maps for the three catchments.

Table 2.5: Water Quality estimates derived using Sentinel 2 MSI spectral bands and indices through stepwise multiple linear regression models. R^2, MSE, RMSE and MAPE of each model are included to evaluate overall model performance.

WQ	Model	R^2	MSE	RMSE	MAPE	Pr > F
DO	**DO** = 2,4896+14,5231*B04+8,5241*NDTI	0,47	1,63	1,28	40,94	<0,0001
EC	**EC** = 141,7760+265,6664*B08+70,4027*AWEInsh+470,7626*NDTI	0,84	412,29	20,31	12,09	<0,0001
TDS	**TDS** = 83,1879+178,4408*B07+51,4416*AWEInsh+275,5208*NDTI	0,86	134,95	11,62	10,69	<0,0001
SAL	**SA**L = -0,2524+3,2901*B03	0,59	0,009	0,09	65,36	<0,0001
pH	**pH** = 10,6670-43,4249*B04	0,25	9,84	3,14	17,29	0,000
Temp	**Temp** = 17,3726+92,8243*B05-51,9519*B08+5,7187*mNDWI plus VI+4,4594*LSWI plus VI-37,8944*NDTI	0,66	1,43	1,196	3,638	<0,0001

2.5.3 Satellite-derived Water quality for Letaba, Keiskamma and Mthatha Catchment

Atmospherically corrected Sentinel 2 MSI images for Letaba, Keiskamma and Mthatha Catchment of January and February 2021 (coinciding with field data collection dates) were used to map the spatial distribution of water quality parameters, using optimum regression models (Table 2.5). The water quality maps generated in this study are depicted as follows; Letaba catchment (Figure 2.8-2.10), Mthatha catchment (Figure 2.11) and Keiskamma (Figure 2.12-2.14). Figure 2.5 shows the spatial distribution of dissolved oxygen in the upper, middle and lower streams of the Letaba Catchment. For instance, Figure 2.8 (a) shows that DO was highly concentrated in the middle of the Tzaneen dam in the upper catchment. The results show that DO decrease outwards when moving from the centre of the dam. The maps also show that the highest predicted DO ranged from 4,98 to 5,42 mg/L in the upper catchment (Figure 2.8-a), then 4,89 to 5,79 mg/L in the middle catchment (Figure 8-b) and 5.85 to 9.70 mg/L (figure 5c) in the lower catchments. Similarly, Figure 2.8 (d) showed a high concentration of EC at the centre of Tzaneen dam, in the upper catchment of the Letaba river and there has been an observable decrease in EC from the upper catchment to the lower catchment as depicted by Figure 2.8(e), and Figure 2.8 (f). The lowest EC (55,35 -161,59 S/m) was estimated in the upper and lower regions of the Letaba River catchment when compared to the middle with EC ranging from 116,80 to 178,23 S/m.

Salinity distribution for the upper, middle and lower catchment regions of Letaba is shown in Figure 2.9 (g, h and i). Tzaneen dam on the upper catchment (Figure 2.9-g) had evenly distributed salts, with high concentrations observed in the southern tip of the dam. Similarly, for the Letsitele portion of Letaba River in the middle catchment, the salinity was relatively homogenous across the river (Figure 2.9-h). Whereas, the lower catchment has relatively high salinity concentrations with maximum salinity levels ranging from 0.49 to 1.15, which is the highest across the entire catchment. The middle (Figure 2.9-k) and lower (Figure 2.9-l) catchment portrayed the highest (3.65 -174 mg/L) total dissolved solids in the Letaba catchment when compared to the upper catchment (Figure 2.9-j) (22,15-169, 14 mg/L). Figure 2.10(n-p), shows that pH is evenly distributed across the catchment area, with the lower catchment having relatively low pH (figure 2.7-p). The model also predicted abnormal surface temperature in the Letaba river catchment (Figure 2.10 q-s), especially in the northern part of the upper catchment (Tzaneen dam – figure 2.10-q) with the highest ranging from 27.70 to 37,83°C and the lower catchment (Figure 2.10s) with the highest ranging from 28 to 38°C. This might be associated with model errors in predicting surface water temperatures. Whereas, the middle catchment had the lowest average temperatures of approximately 18 to 27°C.

Figure 2.11 (a-f) shows the distribution maps of DO, EC, PH, TDS, Temperature and Salinity in the middle reaches of the Mthatha catchment. Due to high cloud coverage in both, the upper and lower regions of the Mthatha catchment during the study period, cloudless satellite data could not be acquired, therefore the areas were excluded during the analysis of the images. Figure 2.8-a shows the spatial distribution of Dissolved Oxygen (DO) across the middle region of the Mthatha catchment. The DO values ranged from 3.36 to 8.74 mg/L. There are also observable high concentrations of DO in the eastern section of the Mthatha dam. While, Figure 2.11-b, shows that EC is evenly distributed across the Mthatha dam, with a slight variation on the northern section of the dam. The results of the study, in Figure 2.11-c, show that high pH in the Northern region of Mthatha dam, ranging from 0.81 to 9.03. Figure 2.11-d, shows that the Mthatha dam had high concentrations of TDS in the lower regions (Southern) when compared to the upper regions (north of the dam). The predicted TDS in the dam ranges from 50.31 to 178.9 mg/L. Temperature (Figure 2.11-e) is an important factor to consider when assessing water quality. In addition to its own effects, temperature influences several other parameters and can alter the physical and chemical properties of water. In this regard Figure 2.11(e), shows that temperature is homogenous across the Mthatha dam, except in the northern portion whereby temperatures range as low as 5.13-16.81°C. Whereas, Salinity (Figure 2.11-f) is highly concentrated in the eastern part of the Mthatha dam, with the northern part having the lowest concentrations ranging from 0.07 to 0.10.

In the Keiskamma catchment, the DO composition is highest in the middle part of the middle catchment (4.84-5.73) and lowest in the middle part of the upper catchment (4.54-4.75) (Figure 2.12: a-c). The lower catchment has average DO composition (4.72-5.33) which is mostly concentrated at the river mouth. The concentration of EC is highest in the middle catchment (224.88-335.25) but EC in the lower catchment covers a large surface area with a lesser concentration (212.74-243.32) (Figure 12: d-f). The upper catchment had the least EC composition (194,66-211.63). Moderate concentrations of pH have been observed in the lower section of the Tyume river dam in the upper catchment (Figure 13: G). While the middle and the lower catchments (Figure 2.13: H-I) are portrayed to have a high concentration of PH, especially towards the Indian Ocean. However, the trend follows a different pattern when it comes to salinity, for instance, Figure 2.13: K shows that there's a high concentration of salinity in the lower catchment towards the sea when compared to the middle and the upper catchment.

Salinity ranges from 0,42-0,66 in the upper catchment (Tyume River dam), then 0,39 -0,88 in the middle catchment and 0,47-1,10 in the lower catchment, especially in the river mouth (Figure 2.13: J-K). Total Dissolved Solids also follow a similar pattern to the other water quality parameters, (Figure 2.14: M-O). The TDS concentrations increase from the upper catchment to the lower catchment. TDS follow a normal river flow profile. Similarly, water temperature (14: P-R) also increases from the interior (upper catchment) to the shoreline (lower catchment). Most interestingly, similar trends were observed for other catchments. Overall, the water parameters considered study provided fairly a detailed overview of the state of the environment within the three catchments. However, we hope that the water quality parameters that still need to be received from the water lab will confirm the observed trends as the current report is only based on physicochemical parameters. These lab analysis findings will be thus on the final WRC project report, once the results are received.

Letaba Catchment: Upper Middle Lower

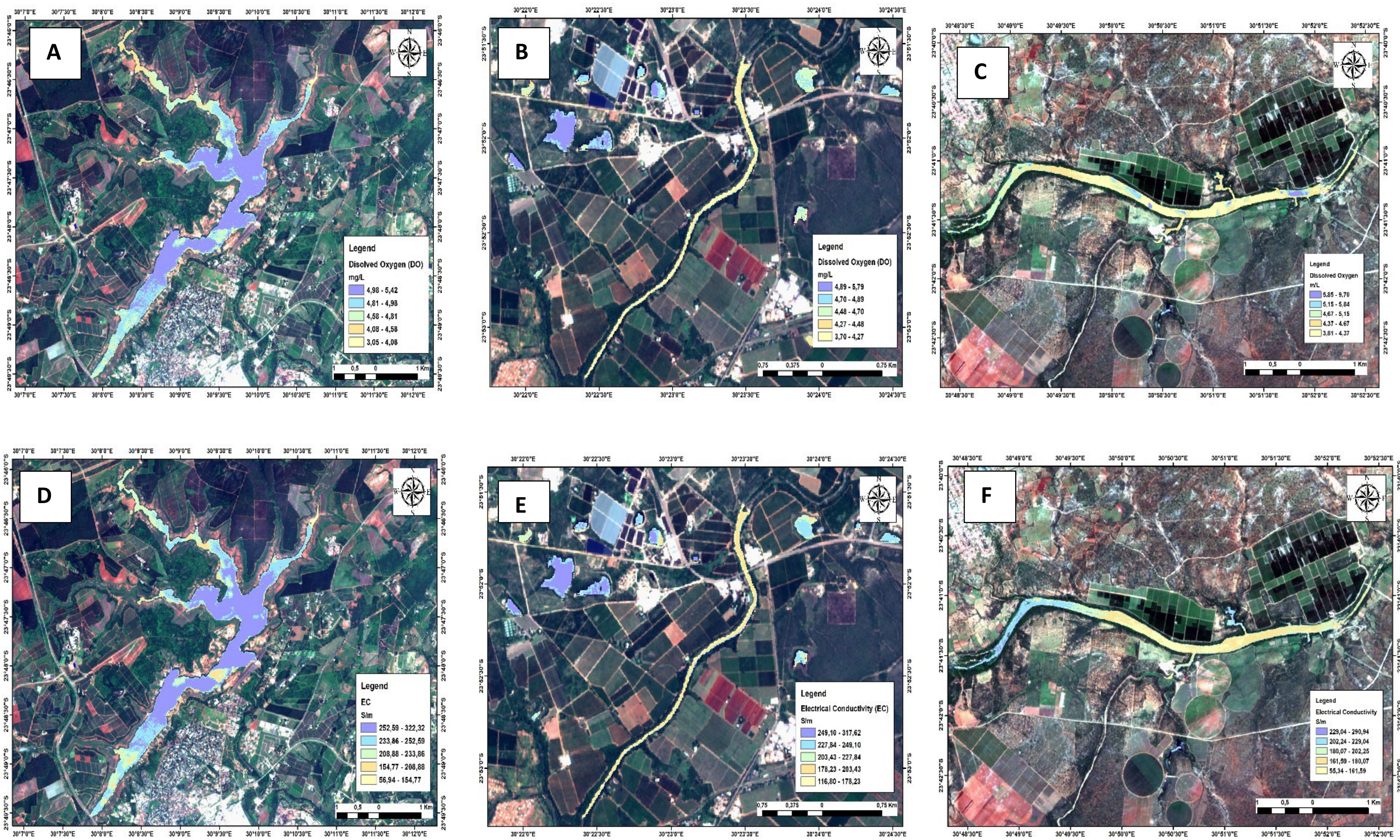


Figure 2.8: Sentinel 2 derived distribution map of Dissolved Oxygen (DO) (a-c) and Electrical conductivity (d-f) in the Letaba river catchment.

Letaba Catchment: Upper Middle Lower

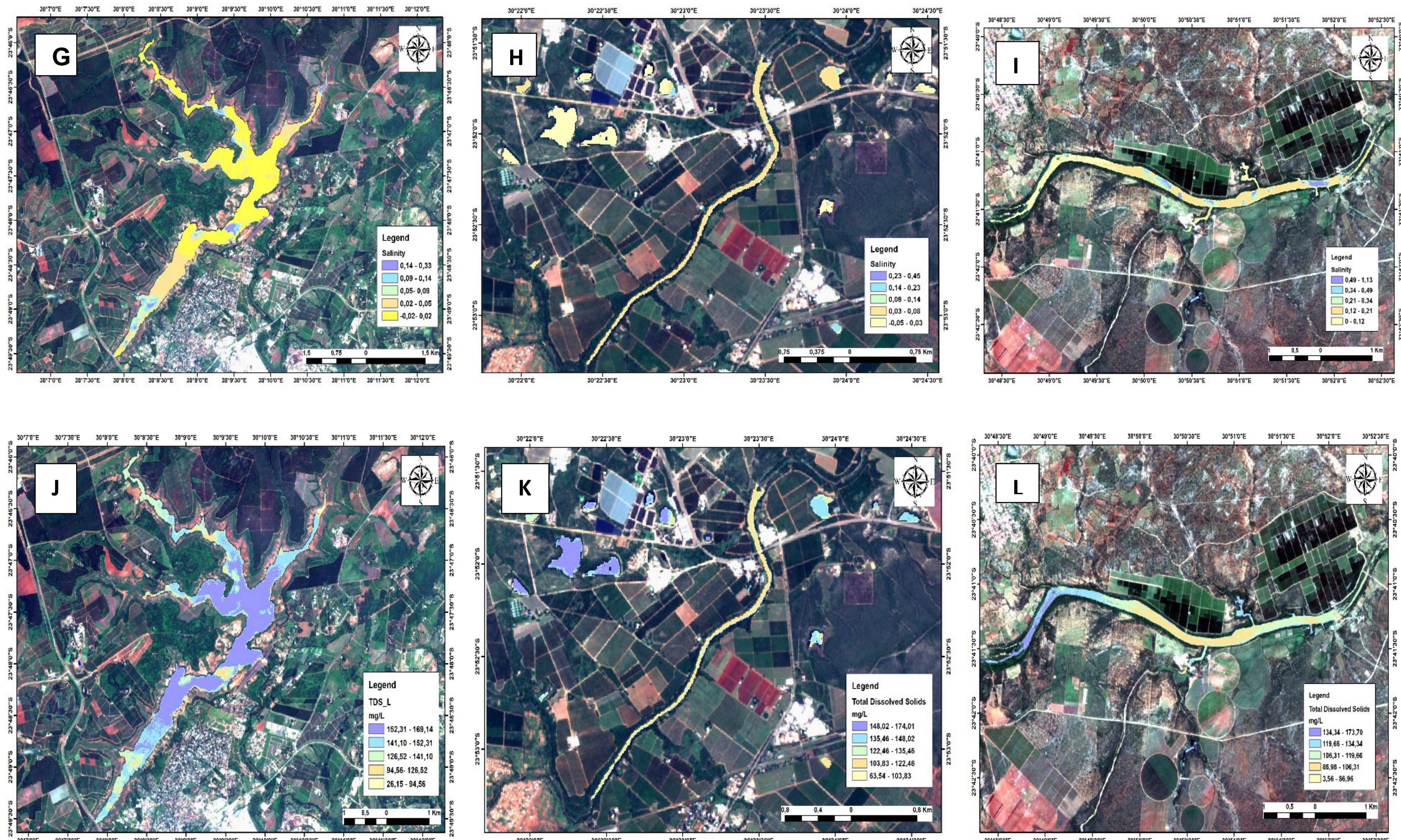
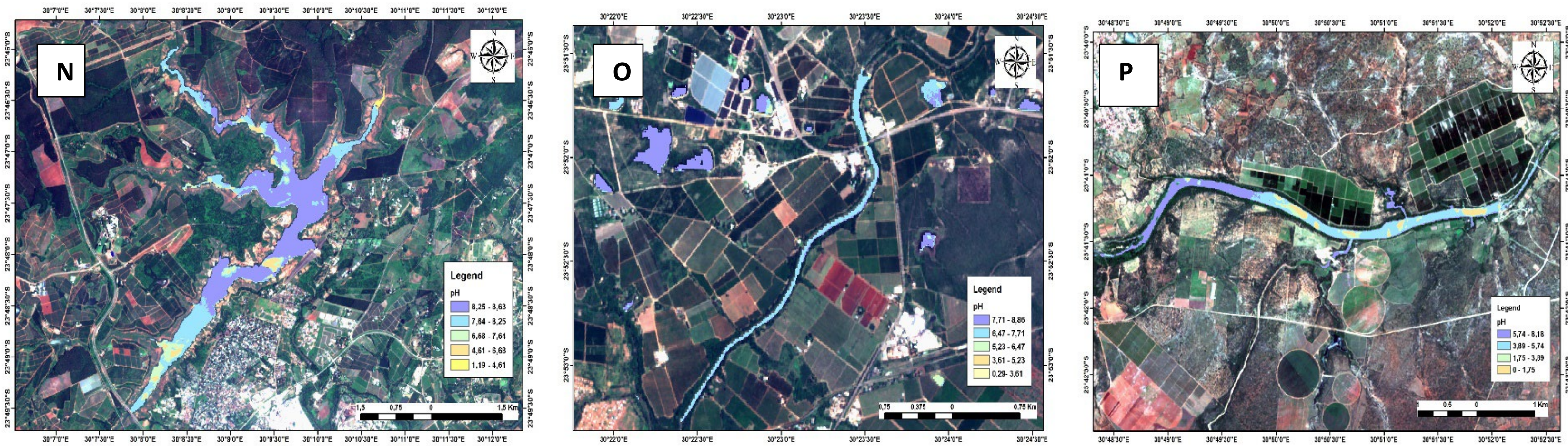


Figure 2.9: Sentinel 2 derived distribution map of Salinity (g-i) and Total Dissolved Solids (j-l) in the Letaba river catchment.

Letaba Catchment: Upper Middle Lower



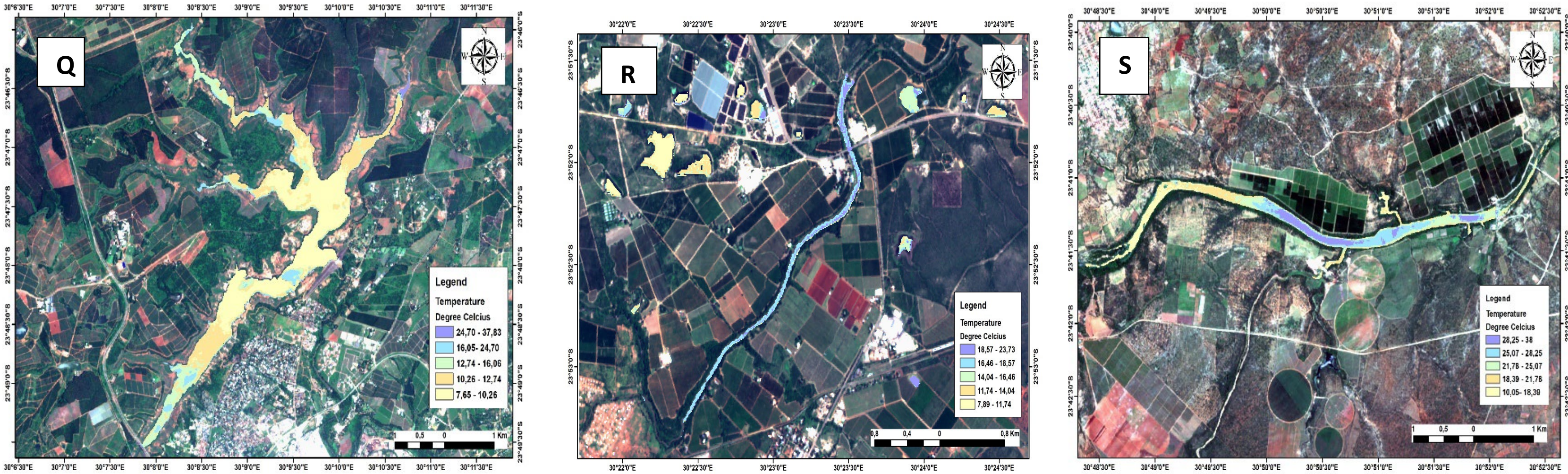


Figure 2.10: Distribution map of pH (n-p) and Temperature (q-s) in the Letaba river catchment.

Mthatha Catchment: Upper **Middle** **Lower**

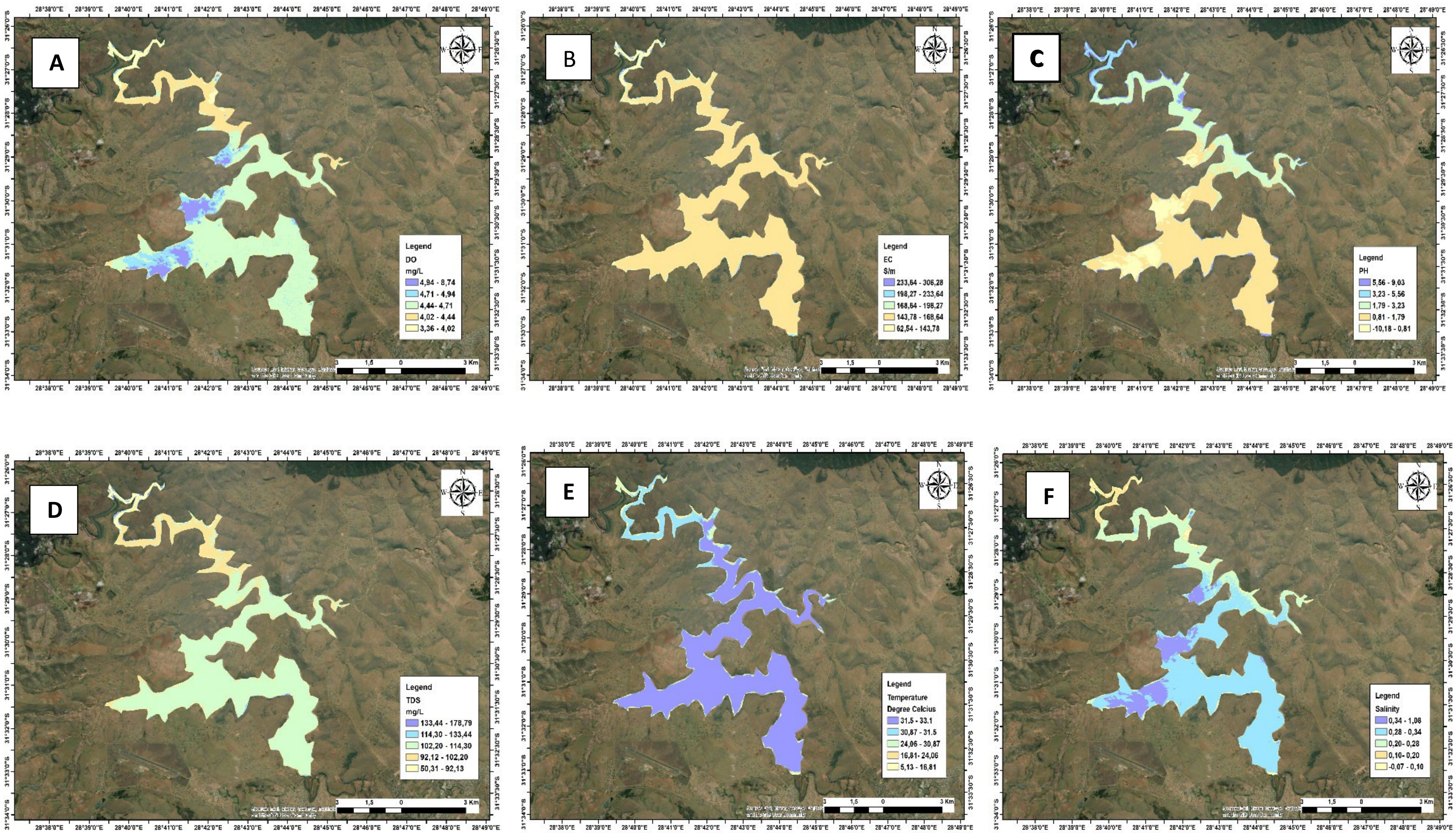


Figure 2.11: Distribution map of DO, EC, PH, TDS, Temperature and Salinity in the Mthatha catchment.

Keiskamma Catchment: **Upper** **Middle** **Lower**

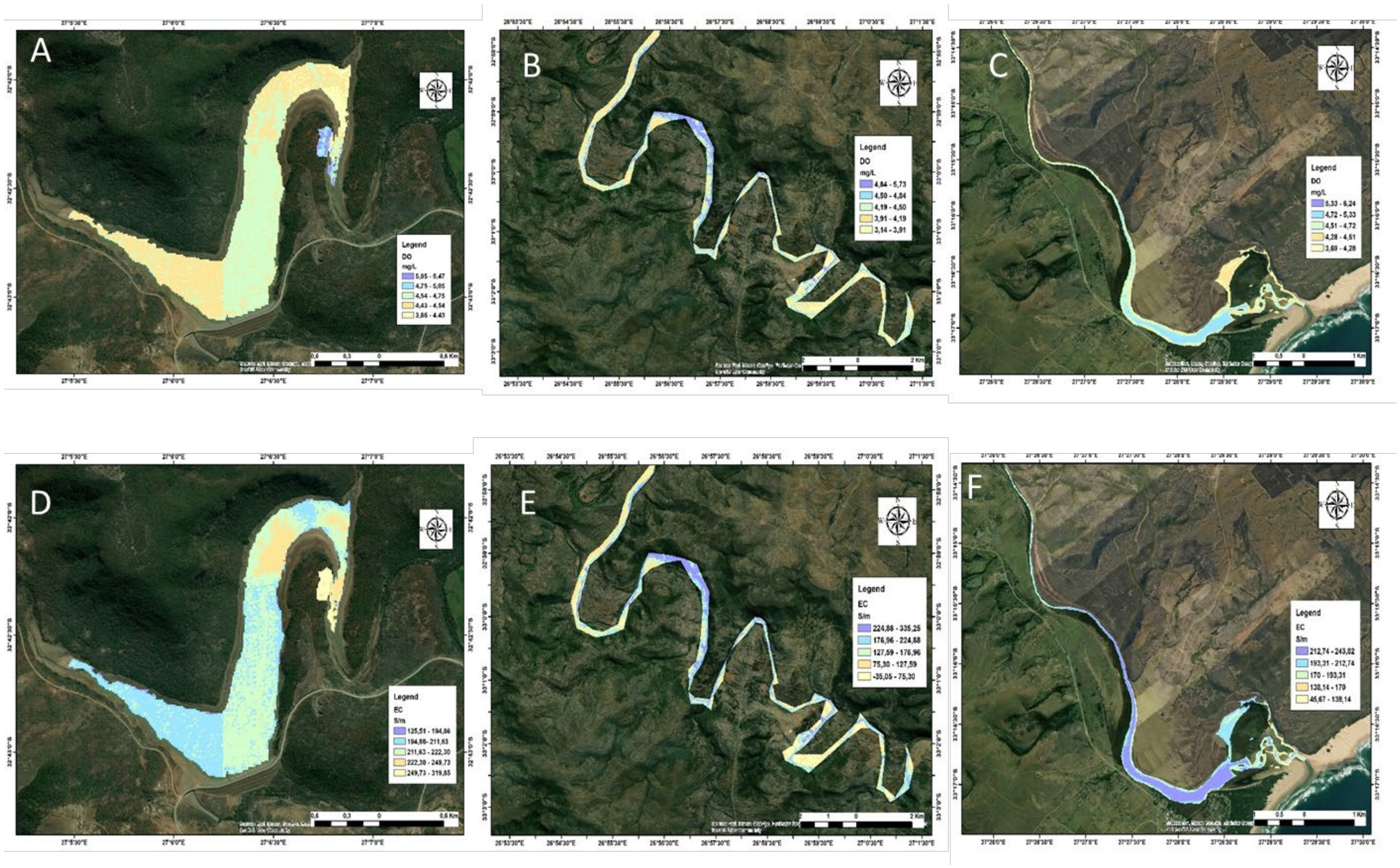


Figure 2.12: Distribution map of DO (A-C) and EC (D-F) in the Keiskamma catchment.

Keiskamma Catchment: Upper Middle Lower

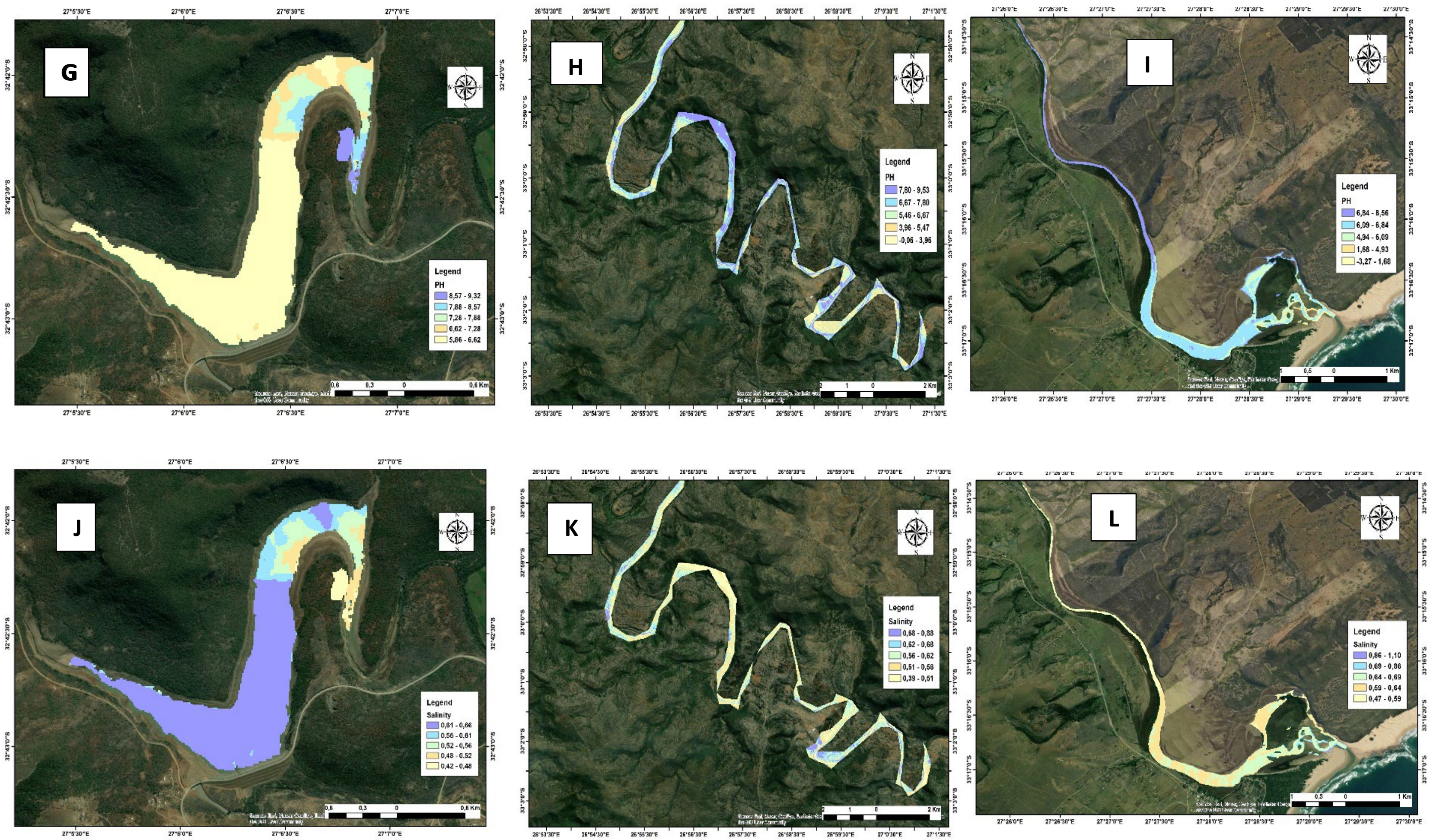


Figure 2.13: Distribution map of pH (G-I) and Salinity (J-L) in the Keiskamma catchment.

Keiskamma Catchment: Upper Middle Lower

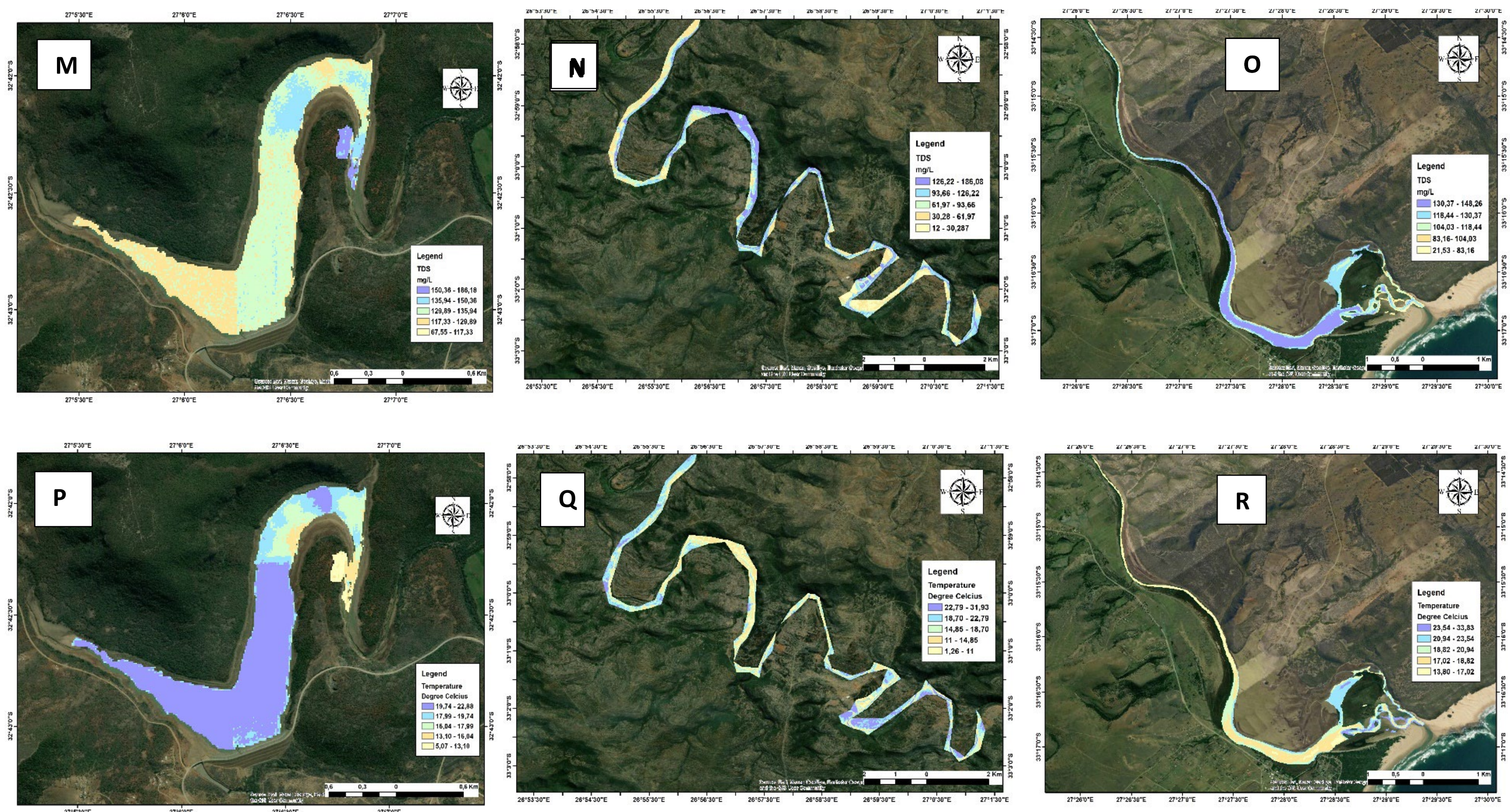


Figure 2.14: Distribution map of TDS (M-O) and Temperature (P-R) in the Keiskamma catchment.

2.5.4 Satellite-derived surface waterbodies for Letaba and Keiskamma River catchment

To map water bodies in the three catchment areas under study the Modified Normalised Difference Water Index (MNDWI) was calculated using the Sentinel 2 MSI band combination involving band 4 and band 8. MNDWI uses green and SWIR bands for the enhancement of open water features. It also diminishes built-up area features that are often correlated with open water in other indices (Xu, 2006). Figure 2.15 shows the spatial distribution of water bodies in the Letaba and Keiskamma river catchment for February and January 2021 derived using MNDWI. Figure 2.15 shows that water bodies in the Letaba catchment are distributed along both Groot and Klein Letaba Rivers, with the rivers flowing from west to east. Tzaneen dam in the western part is the largest water body observed in the Letaba river catchment area. Whereas, Figure 2.15 portrays a water map of the Keiskamma river catchment. The map shows scattered water bodies in the upper region of the Keiskamma river catchment as well as the lower region towards the Indian Ocean. The largest water bodies detected in the Keiskamma river catchment include; the Sandile dam and Tyume river dam. Due to the lack of cloudless Sentinel 2 satellite data for the Mthatha catchment during the January and February 2021 study period, reliable water body maps could not be generated, as a result, they were excluded from these results. Consequently, Spatio-temporal changes in water quantity in the three catchments were quantified using historical data.

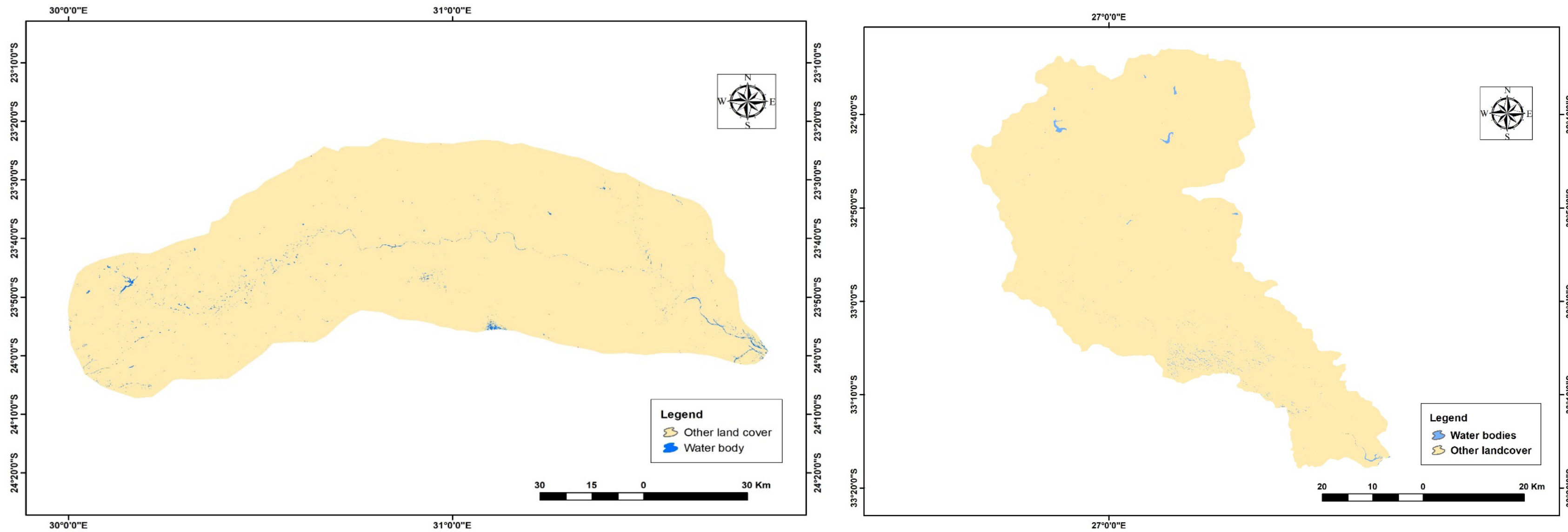


Figure 2.15: Satellite-derived surface waterbodies for the three selected catchments.

The total area covered by water in the Letaba catchment increased by 717 ha in 1994 to 1889 ha in 2020, increasing the percentage composition of the total catchment area from 0.08% to 0.20% (Table 2.6 and Figure 2.16). Thus, for the period 1994 to 2020, water bodies increased by 0.13%. The quantity of water in the Keiskamma catchment fluctuated over the period from 1994 to 2020. The water quantity decreased from 8125 ha in 1994 to 2934 ha in 2005 representing a -1.92 percentage change. However, the catchment saw a huge increase in the water quantity from 2005 to 2020 where a 3.03% change in the area covered was observed. Overall, there was a 1.11% change in water quantity in the Keiskamma from 1994 to 2020. On the other hand, Mthatha was the only catchment to see a continuous decrease in water quantities from 1994 to 2020 (Table 2.6 and Figure 2.16). In the Mthatha catchment, water quantity decreased from 14152 ha in 1994 to 4758 ha in 2020, which represents a -3.65% change in the overall composition of water bodies.

Table 2.6: Satellite-derived catchment-scale surface area for waterbodies for the three selected catchments

	Area (ha)			**% composition**			**% change**		
Catchment	**1994**	**2005**	**2020**	**1994**	**2005**	**2020**	**1994-05**	**2005 - 20**	**1994 - 20**
Mthatha	14152	4 914	4 758	5,49	1,91	1,85	-3,59	-0,06	-3,65
Keiskamma	8 125	2 934	11109	3,01	1,09	4,11	-1,92	3,03	1,11
Letaba	717	1110	1889	0,08	0,12	0,20	0,04	0,08	0,13

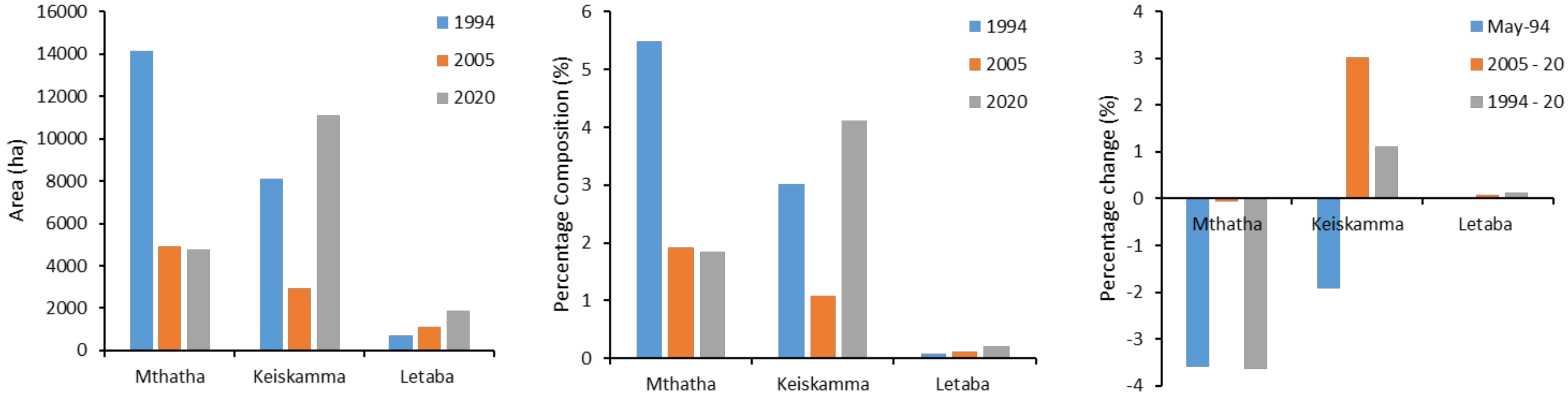


Figure 2.16: Graphs showing changes in surface area for waterbodies.

2.6 Conclusion

The project assessed the effects of land use and land cover change on water quality and quantity within the three selected catchments in South Africa. The study objective was built up on the WRC C2019/2020-00166 project Chapter 1, which focussed on land use and land cover characterisations. Land use and land cover change results as reported in Chapter 1 demonstrated significant cover changes within the three catchments with major changes noticeable in the upper, middle and lower reaches of the three catchments. Water quality and quantity assessment and monitoring followed the observed LULC changes within the three catchments and the results demonstrated significant variations in water quality across the catchments. Overall, the study finding showed a high concentration of water quality parameters in the lower reaches of the catchments. For example, their physicochemical parameters namely; dissolved oxygen, pH, temperature total dissolved solids, and electrical conductivity were high in the lower reaches of the Letaba catchment. However, for the Keiskamma catchment, the DO concentrations were found to be higher and slightly lower in the middle and lower reaches of the catchment. Satellite derived water quality maps demonstrated visible spatial variability for all the parameters across the three catchments. Although the project results demonstrate high concentrations of water quality parameters in the three catchments, there is a need to compare the concentrations with the South African Water Quality and World Health Organisation recommended standards for drinking and agriculture to determine whether these systems are heavily polluted. The findings of the study demonstrate that land use and land cover have directly and indirectly affected the water quality of the catchments. For water quantity, the results showed that in the Letaba catchment, the surface area covered by water constantly increased during the study period whereas for Keiskamma noticeable fluctuations were noted over the monitoring period. However, for the Mthatha catchment unlike the other two catchments, a significant decline in the surface area was observed. These findings underscore the relevance of remotely sensed spatial explicit methodologies assessing the impacts of LULCC on water quality and quantity. However, there is a need for future consideration of the possible impacts of climate change and variability on surface water resources. It is however imperative to note that the water quality report section is mainly based on the analysis of physicochemical parameters since the lab water quality analysis was yet unavailable during the reporting period. Nonetheless, it is assumed lab analysis results will further confirm the observed water quality trends observed within the three catchments. The lab analysis results will thus be on the final WRC project report.

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Chapter 3: Report on the pollutant sources in the three catchments in South Africa

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3.1 Abstract

Land use-land cover (LULC) changes, climate change and variability are the principal drivers triggering land, and water quality and quantity degradation. This stems from anthropogenic activities, such as forestry, agriculture, mining, industrialisation and urbanisation which often lead to land use change and increased effluent discharge into water bodies. These activities also tend to increase runoff from different sources including, paved surfaces in urban areas and poorly managed croplands, leading to increased transport of pollutants into surface water bodies affecting water quality. Highly mobile nutrient ions, such as nitrate fertilisers, can infiltrate surface water and aquifers and contaminate the water supply as a result of the excessive and indiscriminate application in numerous agricultural areas. Likewise, the increased number of settlements caused by a burgeoning human population exerts excessive pressure on sewage treatment plants, thereby degrading the effluent quality discharged into surface waters. Surface water contamination can be from point and non-point sources. Point source pollution could be from sewage effluent, industrial effluent, backyard industry discharges and mining activities, while runoff from urban and cultivated lands could be non-point pollution sources. This report presented here focuses on some of the identified pollutants from the Letaba, Keiskamma, and Mthatha Rivers, as well as their isotopic concentrations, to trace their source.

3.1 Deliverable aim

The aim of this chapter is to report on the application of isotope techniques to identify the sources of the pollutants, in the Letaba, Keiskamma and Mthatha catchments, particularly nitrates.

3.2 Study area description

3.2.1 Letaba River Catchment

The Letaba River catchment is located between longitudes 30°0′ and 31°40′ East and latitudes 23°30′ and 24°0′ South, in the Mopani District of Limpopo Province, South Africa (Figure 3.1). The Letaba River catchment has a surface area of 67,000 km^2. The Letaba River flows eastwards across the Kruger National Park (KNP), where it joins the Olifants River a short distance upstream of the Mozambique border. The river catchment basin comprises six large dams from upstream to downstream including Ebenezer Dam, Tzaneen Dam, Modjaji Dam (in the Molototsi River), Hudson Ntsanwisi Dam (in the Nsama River), Middle Letaba Dam (in the Middle Letaba River) and Engelhard Dam. These dams are the major sources of water supply to Tzaneen, Polokwane, Phalaborwa, and villages scattered around the catchment and also agricultural and mining water users. Some of the major tributaries of the Letaba River include; the Nharhweni River, Ngwenyeni River, Klein Letaba River, Molototsi River, Groot Letaba River, Nwanedzi River, and Makhadzi River.

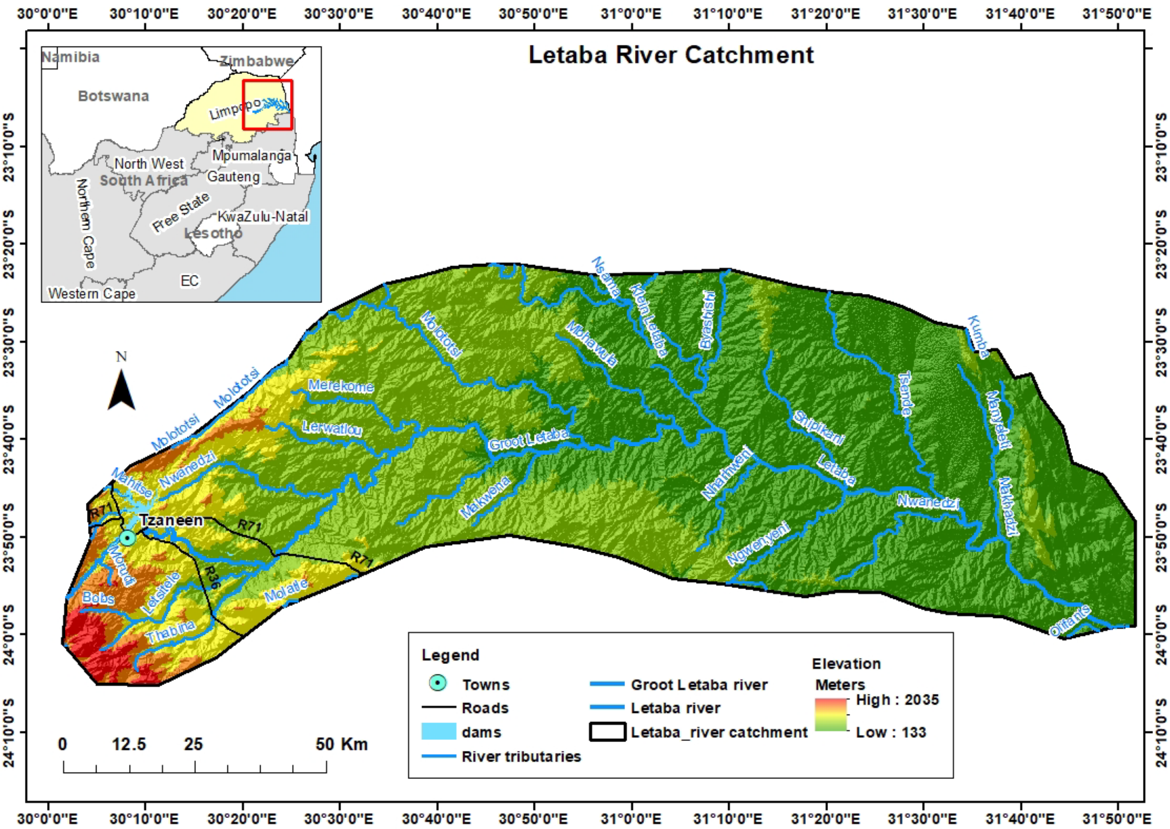


Figure 3.1: Letaba River catchment

3.2.2 Keiskamma River Catchment

The Keiskamma is one of the largest catchments in the semi-arid region of the Eastern Cape Province of South Africa, covering an area of 2 745 km² which forms approximately 35% of the former Ciskei region (Figure 3.2). The Keiskamma is the main river in the catchment with headwaters situated in the Amatole Mountains above Keiskammahoek town. It flows eastwards for 263 km and drains into the Indian Ocean at the resort town of Hamburg (33°17´S 27°29´E). The main tributaries of the Keiskamma River are Tyume, Chalumna and Gulu, with the Tyume headwaters in Hogsback. Large areas in the escarpment zone are protected and its land cover conditions can be described as pristine.

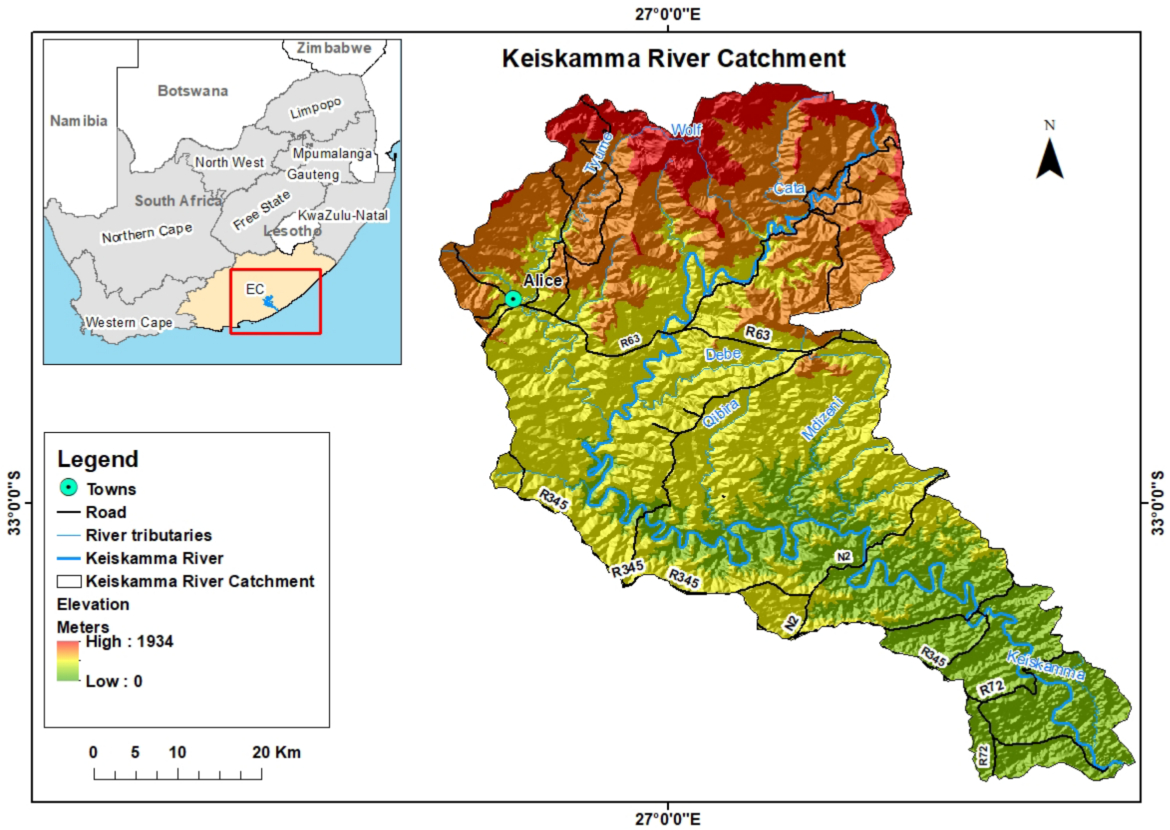


Figure 3.2: Keiskamma River catchment

The catchment is explicitly categorised into three topographic zones, that is escarpment, plateau and coastal zones. The escarpment zone receives higher rainfall and mostly comprises protected mountain forests, whereas the plateau zone encompasses communal settlements where land degradation in the form of soil erosion, vegetation invasions and reduction, are among the key environmental problems. These problems have been aggravated by increased and uncontrolled land-use practices, resulting in a major impact on the water quantity and quality of the Keiskamma River.

1.2 Mthatha River Catchment

Mthatha River Catchment lies between latitudes 31°36'29.19"S and Longitudes 28°49'30.05"E. The catchment is located in the T20 tertiary catchment, which lies within the Mzimvubu to Keiskamma Water Management Area (WMA 12) (proposed new WMA is Mzimvubu to Tsitsikamma WMA 7 – Government Gazette 35517, Notice No. 547, 20 July 2012). Mthatha river catchment is situated in King Sabata Dalindyebo and Nyandeni Local Municipalities of the O.R Tambo District Municipality in the Eastern Cape Province. The perennial Mthatha River originates in the Drakensberg at 1400 m elevation, it is approximately 250 km long and 50 km wide and covers an area of about 5 520 km^2. Mthatha River Catchment consists of the main river (Mthatha River) which is approximately 250 km long with two large tributaries which wind their way to the sea north of Coffee Bay.

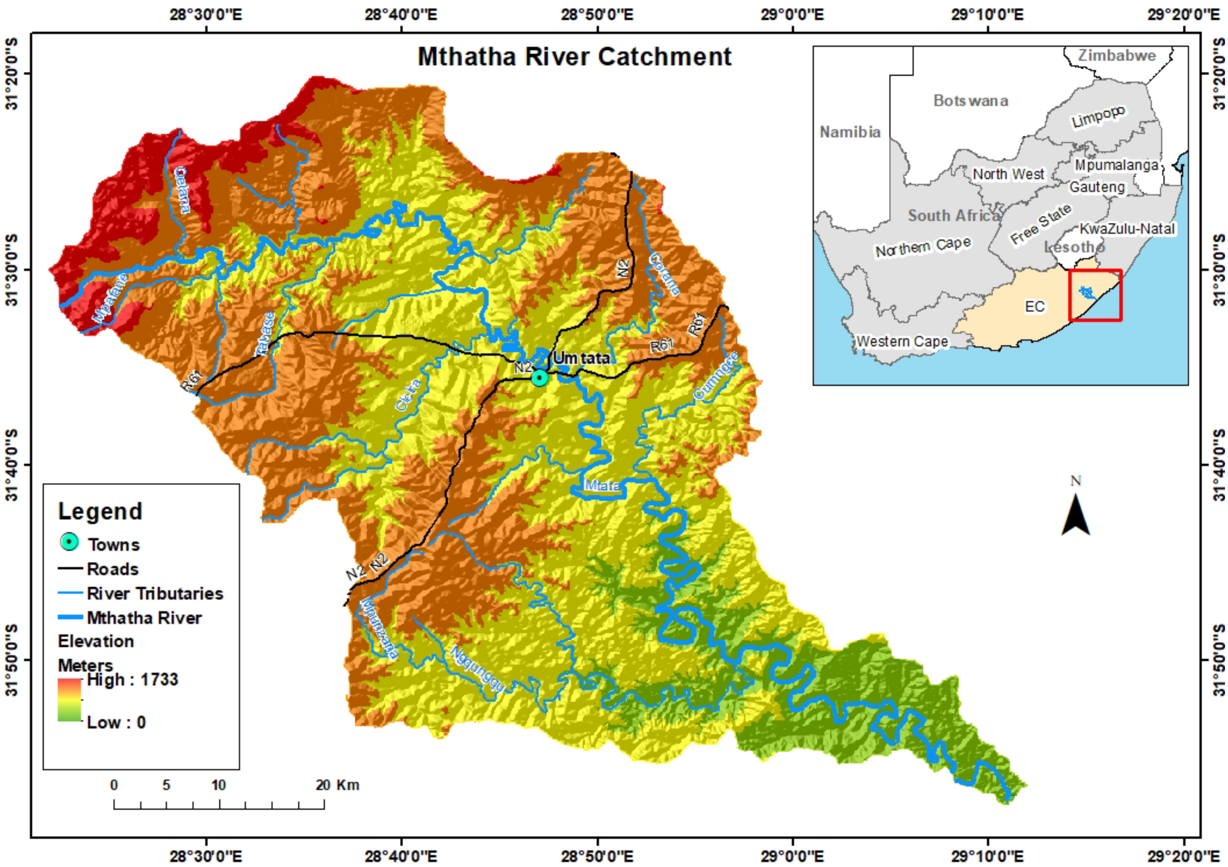


Figure 3.3: Mthatha River Catchment

The catchment comprises predominantly mountainous and valley tops. The vegetation is largely grassland with some natural and commercial plantations. The topography of the King Sabata Dalindyebo and Nyandeni Municipalities is incised with large river valleys and floodplains that run on a northwest-southeast axis. The inland areas, which typify the study site, could be described as undulating to hilly, with moderate to steep slopes. The landscape is interspersed with grassland areas and patches of forest, with the river valleys covered by a thicket. The upper catchment area includes the Mthatha River headwaters and the Qelana tributary. The uppermost regions of the headwaters are still in a natural state as they are not accessible to humans and cattle. The upper reaches are mainly covered by commercial forest plantations. Commercial water use is dominated by forestry-related industries (Langeni and KwaBhaca sawmills), followed by the industrial, urban and rural sectors. The agricultural sector is poorly developed within the catchment with scattered subsistence small-scale irrigation throughout the catchment and particularly in the middle and lower reaches of the catchment using water pumped directly from the rivers using pumps. The Mthatha town is located in the middle reaches of the catchment and is predominately covered by built-up areas, factories and industries. Informal settlements naturally cluster near employment opportunities, such as the timber mills in Ugie and Mthatha towns. Patches of grassland are open for grazing areas. Subsistence farming and forestry are the main land use in the catchment. A few natural areas exist, mainly around the steep valleys towards the coast.

3.3 Materials and Methods

3.3.1 Field data collection

Seasonal sampling was carried out (2021) at different sites of the Letaba, Keiskamma and Mthatha rivers. The sites were selected based on land use or land cover in the upstream, midstream and downstream of the three rivers. Physicochemical variables, such as temperature, pH, dissolved oxygen, total dissolved solids (TDS), electrical conductivity (EC) and salinity were measured *in-situ* using a YSI 556 Multi Probe system; a handheld multi-parameter instrument. Two sets of surface water (500 ml) samples up to a depth of 10 cm were collected using acid pre-treated sampling bottles. The samples were kept in cooler boxes with ice and transported to the laboratory. At the laboratory, the samples were filtered with a 0.45 µm membrane filter and 10 ml nitric acid was added to preserve the samples. The samples were then refrigerated at 4^{o}C before chemical analysis.

3.3.2 Sediment and soil analysis for lead (Pb) analysis

Sediment samples from the bottom of the middle section of each of the three catchments in sterile plastic bottles. Approximately 3 kg of the top sediments at each site were collected using a hand trowel. The samples were then transported to the laboratory in ice-packed boxes and were frozen before chemical analysis by inductively coupled plasma-optical emission spectrophotometer (ICP-OES) for estimating metal and isotope concentrations. Soil samples were also collected from the topsoil (top 20 cm) of the nearby land use system that was within a 1 km radius of the river. The soil samples were air-dried before being packed and sent for lead analysis at Ghent University in Belgium for isotope analysis.

3.3.3 Lead (Pb) analysis of sediment and soil samples

The analysis of the sediments and soil samples consisted of microwave-assisted acid digestion to achieve complete mineralization of the soil. The purification of the samples was performed using the Sr Spec resin. The concentration of the pure Pb fraction was measured on an Agilent 8800 QQQ-ICP-MS and the isotopic analysis was performed on a Neptune MC-ICP-MS instrument bracketed by a Pb NIST standard and Tl as an internal isotopic standard. Pb was selected as an isotopic signature to trace the heavy metal contamination as it was found in relatively higher concentrations in the three catchments, mainly in the lower reaches.

3.3.4 Isotopic composition of Lead (Pb) in sediment and soil samples

Introduction

Heavy metals such as lead (Pb), mercury (Hg), arsenic (As) and cadmium (Cd) have been detected as pollutants in many water sources (Olafisoye et al., 2013, Bhardwaj et al., 2020). These heavy metals that pollute the environment, especially water sources, can originate from a variety of sources, including agriculture, mining, manufacturing, domestic waste runoff, and fossil fuel burning, among others (Kapoor and Singh, 2021, Cheng and Hu, 2010). In numerous studies, environmentalists have been able to detect hazardous concentrations of these pollutants in the environment, and determining the exact origins of these toxins is essential for their management. Using isotopes is one of the most dependable and precise methods for tracing heavy metal sources (Cheng and Hu, 2010). Nevertheless, not all heavy metals have easily measurable isotopes that can be used to identify contaminant sources. Heavy metals such as lead, however, have been and can be used to identify sources of pollution. Lead is found in a variety of environmental matrices; hence, its presence in particular contexts can serve as a signal of contamination by other heavy metals. The metal has been used as a tracer of pollutants in some studies (Sun et al., 2011). Lead has four isotopes which are ^{204}Pb (1.4%), ^{206}Pb (24.1%), ^{207}Pb (22.1%) and ^{208}Pb (52.4%) (Sun et al., 2011). The isotope ^{204}Pb (1.4%) is of less interest since its proportion in the environment is very small. The remaining isotopes naturally exist in a ratio of about 1.198 and 2.075 for $^{206}Pb/^{207}Pb$ and $^{208}Pb/^{206}Pb$, respectively. Any ratio that differs from the natural ratio suggests anthropogenic interference or other sources (Sun et al., 2011). If the ratio of the isotopes measured from a suspected source is different from those measured from a contaminated environment, the results suggest that the contaminant, in this case, of Pb, would have come from another source (Cheng and Hu, 2010). However, if the ratio is similar, that would be a strong indication that the Pb would have come from the suspected source. The aim of the study was to apply the use of stable Pb isotopes to identify the sources of heavy metal pollution in three river catchments; Keiskamma, Letaba and Mthatha rivers.

Methodology

Sampling: Soil samples were taken from suspected land uses close to the rivers at various locations within the catchment, together with sediment samples which were collected inside the rivers at the different reaches of the rivers. The samples were collected in 1-L polyethylene containers, acidified with HNO_3, and shipped to a laboratory for analysis. A multicollector inductively coupled plasma mass spectrometer (MC-ICP-MS) was used for the analysis to determine the lead concentration and the lead isotopic composition. An international reference material (SRM 981 common Pb isotopic standard) was used for calibration and analytical control before the samples were measured. The $^{206}Pb/^{207}Pb$ and $^{208}Pb/^{207}Pb$ ratios were measured and the results of the sediment and the soils were compared in each catchment.

Results and discussion

This study used stable lead isotopes ($^{207}Pb/^{206}Pb$, $^{208}Pb/^{206}Pb$ and $^{208}Pb/^{207}Pb$ ratios) to trace the transport of anthropogenic lead pollution within the three rivers and predict future lead level changes in a stream draining the catchments.

The following results were obtained from the analysis of sediments and soils sampled from the three rivers:
In the sediment obtained from the Keiskamma River catchment, the ratios of $^{207}Pb/^{206}Pb$, $^{208}Pb/^{206}Pb$, and $^{208}Pb/^{207}Pb$ were 0.8257, 2.0476, and 2.4799, respectively (Table 3.1). The $^{207}Pb/^{206}Pb$, $^{208}Pb/^{206}Pb$, and $^{208}Pb/^{207}Pb$ ratios in the soil in the same catchment were 0.8271, 2.0476 and 2.4759, respectively.

Table 3.1: The isotopic ratio of Pb in the soil and sediments from the Letaba, Keiskamma and Mthatha river catchments

		207/206			208/206			208/207		
		ratio	2SD	2se	ratio	2SD	2se	ratio	2SD	2se
inhouse		0.9041	0.00012	0.00002	2.1533	0.00035	0.00004	2.3816	0.00026	0.00003
inhouse		0.9041	0.00012	0.00002	2.1533	0.00036	0.00005	2.3816	0.00023	0.00003
1	MSO1	0.8034	0.00012	0.00002	2.0889	0.00031	0.00004	2.6001	0.00031	0.00004
2	LSO1	0.9431	0.00012	0.00002	2.2573	0.00038	0.00005	2.3935	0.00031	0.00004
3	LSd1	0.9083	0.00013	0.00002	2.1973	0.00045	0.00006	2.4192	0.00034	0.00004
4	MSd1	0.8225	0.00012	0.00002	2.0430	0.00037	0.00005	2.4840	0.00026	0.00003
5	KSd1	0.8257	0.00013	0.00002	2.0476	0.00040	0.00005	2.4799	0.00029	0.00004
6	KSO1	0.8271	0.00012	0.00002	2.0476	0.00032	0.00004	2.4756	0.00028	0.00004

(KSd1 - Keiskamma sediment, KSO1 - Keiskamma soil, LSd1-Letaba sediment, LSO1-Letaba soil, MSd1-Mthatha sediment, MSO1-Mthatha soil), SD is the standard deviation and se is the standard error

The $^{207}Pb/^{206}Pb$, $^{208}Pb/^{206}Pb$, and $^{208}Pb/^{207}Pb$ ratios were 0.9083, 2.1973, and 2.4192 respectively in the Letaba sediment, and the $^{207}Pb/^{206}Pb$, $^{208}Pb/^{206}Pb$, and $^{208}Pb/^{207}Pb$ ratio in the soil were 0.9431, 2.2573, and 2.3935 respectively in the catchment. Due to the differences in the Pb ratio observed between the soil and the sediment in the Letaba catchment, the results suggest that the Pb found in the sediment might have come from other sources and not from the areas from which the soil samples were taken.

In the Mthatha catchment, the $^{207}Pb/^{206}Pb$, $^{208}Pb/^{206}Pb$, and $^{208}Pb/^{207}Pb$ ratios were 0.8225, 2.0430, and 2.4840 respectively in the sediment, and in the soil, the $^{207}Pb/^{206}Pb$, $^{208}Pb/^{206}Pb$, and $^{208}Pb/^{207}Pb$ ratio were 0.8034, 2.0889, and 2.6001 respectively. The observed differences between the signatures in soil and sediments especially for 208/207 suggest that the source was also different from the sampled site. However, the small difference observed for 207/206 suggests that some Pb might have come from the sampled sites.

In the Keiskamma the ratios were almost similar for all the ratios determined showing a strong correlation between the Pb in sediment and the soil. The findings at Keiskamma suggest that the Pb found in the sediment was most likely from the areas from which the sample was taken.

A similar Pb isotope signature points towards a connection between the collected samples as found in $^{208}Pb/^{206}Pb$ in the Keiskamma River catchment, however, it might be that there are also other sources with the same Pb isotopic signature. The difference in isotope ratios between the samples could indeed indicate that the Pb from the sediment could be coming from another source with a different isotopic signature than the soil, such as agricultural, municipal, industrial, and landfill drainage waters. Lead is known to be one of the most hazardous environmental pollutants (Morel, 2008; Shi et al., 2008). With the rapid development of industry, anthropogenic Pb has become the major source of lead in the environment and is widespread in the atmosphere, soil, water, plants, and animals (Wang et al., 2013). There are many possible ways that human activities affect the lead in the environment and there is a need to reduce such pollution in the environment.

Conclusion

Stable Pb isotopes of the chemical dataset provided a tool whereby the sources of contaminant Pb and related heavy metals were identified. The isotope ratios revealed differences in the behaviour in different river catchments. In the Mthatha and Letaba catchment, the findings suggest that the Pb contaminant might have originated from other sources other than where the soil samples were taken while in the Mthatha the findings suggest that the Pb came from the areas from which the soils were sampled. The results were however not conclusive as it is also possible for the Pb ratios to be similar but yet coming from another source. It is therefore recommended that all possible sources be sampled to accurately determine where the heavy metal contaminants are coming from. Sources such as air, municipal, industrial, agricultural lands, mining and landfills that are found around the catchments must all be sampled and analysed. Additional research to establish the contribution of various sources is therefore needed. Nonetheless, the lead isotope ratio proved to be a useful tool to characterise the source of lead contamination.

3.3.5 Analysis of nutrients and trace metals

One set of water samples from each site was analysed for nutrients (i.e. nitrates, nitrites, ammonia, total nitrogen, phosphorous (ortho-phosphate), sulphate and turbidity. The other set of water samples was analysed to determine the concentrations of trace metals present in the water using an inductively coupled plasma optical emission spectrometry (ICP-OES) at an accredited chemical laboratory (ISO 17025) in Pretoria.

3.3.6 Statistical analysis

The mean and standard deviation of the respective water chemistry, nutrients and metal concentrations were calculated. ANOVA was performed to determine whether there were spatial variations of the water chemistry, nutrients and metals among the sites and rivers using Statistica (version 10, 2007).

3.4 Results

3.4.1 Physicochemical parameters and nutrients

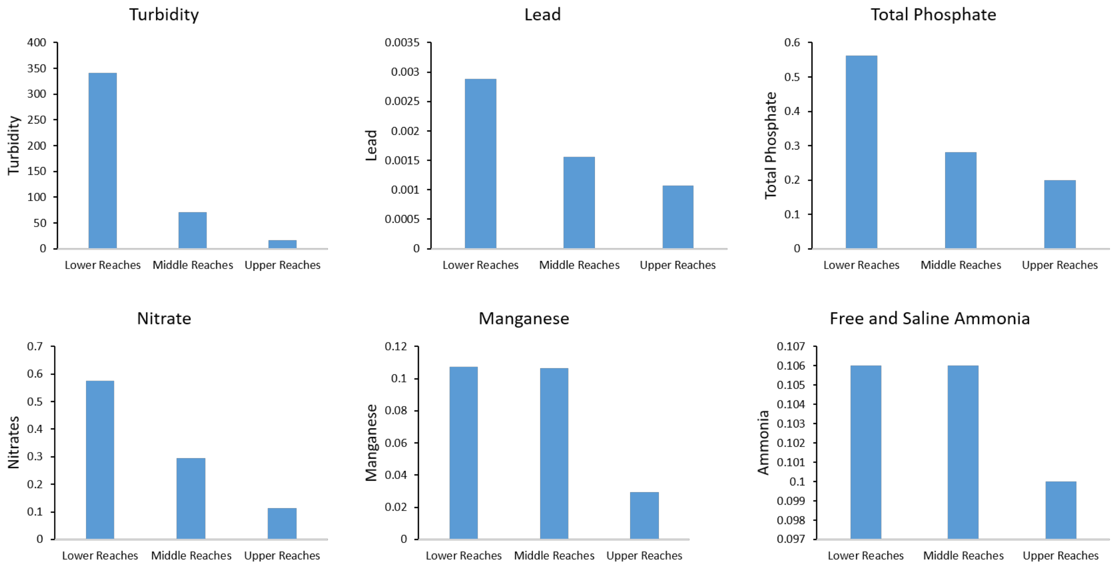
There were significant variations in the physicochemical properties among the three rivers (Table 3.3). The turbidity, nutrients and trace metal concentrations in the Groot Letaba River (Limpopo Province), Keiskamma and Mthatha rivers (Eastern Cape) are shown in Table 3.2. The highest turbidity was recorded at the lower reaches of all three rivers, followed by the middle reaches in both Letaba and Mthatha and then lower reaches. However, for the Keiskamma, the turbidity level at the upper reaches was higher than at the middle reaches. The difference in turbidity levels was significant among the reaches of each river.

Table 3.2:Results for Factorial analysis of physicochemical properties of water in three different rivers

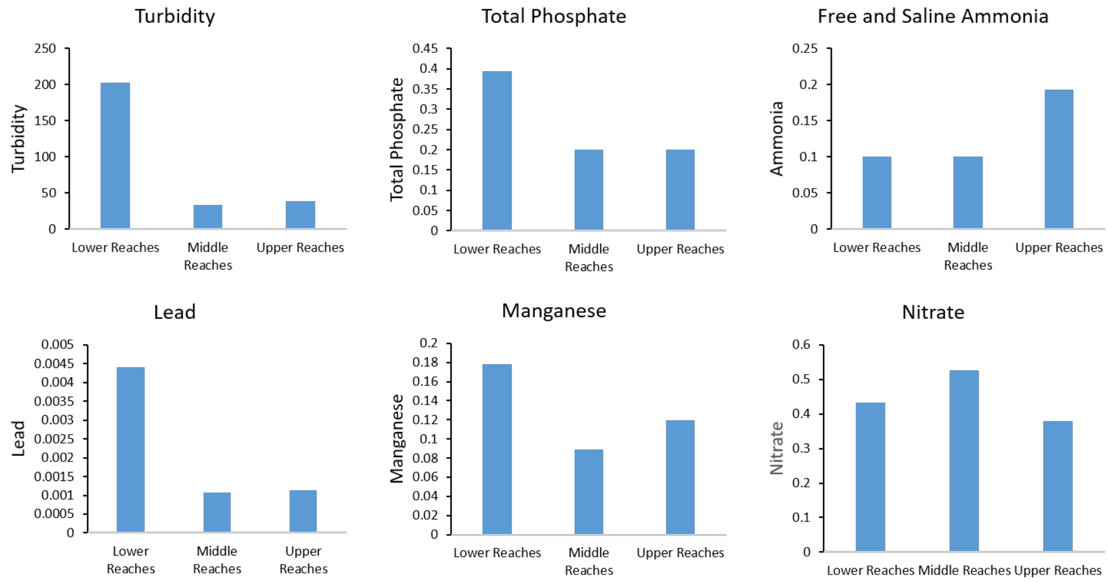
	Turbidity	Nitrate	Nitrite	Total Phosphate	Ortho Phosphate	Free and Saline Ammonia	Arsenic
Catchment	**mg/l**						
Keiskamma	91.33b	0.45b	0.05	0.26	0.10b	0.13b	0.0010b
Letaba	145.10a	0.33b	0.05	0.35	0.10b	0.10b	0.0010b
Mthatha	113.82ab	302.63a	0.05	0.26	0.14a	0.22a	0.0013a
	*	***	ns	ns	***	***	*
River Section	**Turbidity**	**Nitrate**	**Nitrite**	**Total Phosphate**	**Ortho Phosphate**	**Free and Saline Ammonia**	**Arsenic**
Lower Reaches	255.05a	73.63	0.05	0.44c	0.11	0.16ab	0.001
Middle Reaches	83.25b	109.22	0.05	0.23b	0.12	0.12b	0.001
Upper Reaches	22.08c	87.56	0.05	0.23b	0.11	0.17b	0.001
Significance	***	ns	ns	***	ns	**	ns

The nitrate concentration ranged from 0.113 (upper reaches) to 0.575 mg/l (lower reaches) in the Keiskamma River, and from 0.38 mg/l (upper reaches) to 0.527 mg/l (middle reaches) in the Dwars River, and from 0.262 (upper reaches) to 0.369 mg/l (middle reaches) of the Mthatha River. The nitrite concentrations in the Keiskamma and Mthatha rivers were the same at all the three reaches (0.05 mg/l). However, the nitrite concentration was highest at the upper reaches of the Groot Letaba River, though there was no significant difference among the reaches. The levels of ortho-phosphate were generally low and there was no significant difference among the reaches of each of the rivers, however, total phosphate was significant among the reaches in the Keiskamma and Mthatha rivers. Ammonia was significantly different among the sites in the Keiskamma and Mthatha rivers but not in the Letaba River (Figure 3.1).

(a)


Turbidity
400
350
300
250
200
150
100
50
0
Turbidity
Lower Reaches
Middle Reaches
Upper Reaches
Lead
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Lead
Lower Reaches
Middle Reaches
Upper Reaches
Total Phosphate
0.6
0.5
0.4
0.3
0.2
0.1
0
Total Phosphate
Lower Reaches
Middle Reaches
Upper Reaches
Nitrate
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Nitrates
Lower Reaches
Middle Reaches
Upper Reaches
Manganese
0.12
0.1
0.08
0.06
0.04
0.02
0
Manganese
Lower Reaches
Middle Reaches
Upper Reaches
Free and Saline Ammonia
0.107
0.106
0.105
0.104
0.103
0.102
0.101
0.1
0.099
0.098
0.097
Ammonia
Lower Reaches
Middle Reaches
Upper Reaches

(b)


Turbidity
250
200
150
100
50
0
Turbidity
Lower Reaches
Middle Reaches
Upper Reaches
Total Phosphate
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Total Phosphate
Lower Reaches
Middle Reaches
Upper Reaches
Free and Saline Ammonia
0.25
0.2
0.15
0.1
0.05
0
Ammonia
Lower Reaches
Middle Reaches
Upper Reaches
Lead
0.005
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
Lead
Lower Reaches
Middle Reaches
Upper Reaches
Manganese
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Manganese
Lower Reaches
Middle Reaches
Upper Reaches
Nitrate
0.6
0.5
0.4
0.3
0.2
0.1
0
Nitrate
Lower Reaches
Middle Reaches
Upper Reaches

c)

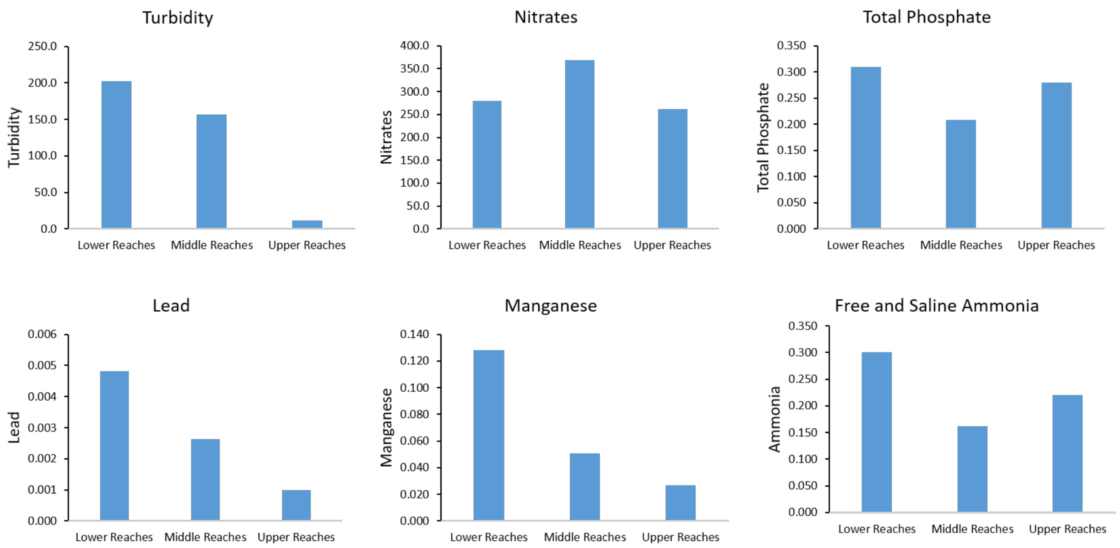


Figure 3.4: Spatial distribution of physicochemical concentrations in the water of (a) Letaba River, (b) Keiskamma River and (c) Mthatha River.

3.4.2 Trace metal concentrations in water

The concentrations of the trace metals varied among the rivers, but only Pb and Mn showed significant differences among the three rivers (Table 3.3). The concentrations of Cd were below the detection level at all the reaches in the Letaba and Keiskamma rivers, and the concentrations of Cd in the Mthatha River were 0.001 mg/l. The concentrations of Cr, Co, Ni and Zn were 0.025 mg/l at all the reaches of the three rivers. The Pb concentrations ranged from 0.0011 at the upper reaches to 0.0029 mg/l at lower reaches in the Letaba River, from 0.001 at the middle reaches to 0.0044 mg/l in the lower reaches in the Keiskamma River, and from 0.001 mg/l at the upper reaches to 0.005 mg/l at the lower reaches in the Mthatha River. There were significant differences among the reaches of all three rivers (Table 3.3).

Table 3.3: Results for Factorial analysis of trace metals in the water of the three rivers

	Cadmium	**Total Chromium**	**Cobalt**	**Lead**	**Manganese**	**Nickel**	**Zinc**
Catchment	**mg/l**						
Keiskamma	0.001	0.025	0.025	0.002b	0.129a	0.025	0.025
Letaba	0.001	0.025	0.025	0.002b	0.082b	0.025	0.025
Mthatha	0.001	0.025	0.025	0.003a	0.063b	0.025	0.025

	ns	ns	ns	*	**	ns	ns
River Section	**Cadmium**	**Total Chromium**	**Cobalt**	**Lead**	**Manganese**	**Nickel**	**Zinc**
Lower Reaches	0.001	0.025	0.025	0.004a	0.138a	0.025	0.025
Middle Reaches	0.001	0.025	0.025	0.002b	0.084b	0.025	0.025
Upper Reaches	0.001	0.025	0.025	0.001b	0.058b	0.025	0.025
	ns	ns	ns	***	***	ns	ns

The concentration of Mn ranged from 0.029 (upper reaches) to 0.107 mg/g (lower reaches) in the Letaba River, from 0.088 to 0.178 mg/g (lower reaches) in the Keiskamma River, and from 0.026 to 0.128 mg/g (lower reaches) in the Mthatha River. There were significant differences among the reaches of the Letaba and Keiskamma rivers, but there was no significant difference among the reaches of the Mthatha River.

3.5 Discussion

All nitrate readings were below the World Health Organization's (2011) recommendation threshold of 50 mg/l. Except for the middle reaches of the Mthatha River, the amounts of ortho-phosphate were relatively low at all sites. This may be the result of fertiliser runoff from agricultural areas or inadequately treated wastewater released into the river. The most common sources of phosphorus in South African freshwater systems include agricultural effluent and sewage, with a substantial phosphate load resulting from detergents, especially washing powders (Griffin, 2017; Nhiwatiwa et al., 2017). Excessive amounts of phosphorus in aquatic systems can lead to algal blooms, which can result in decreased dissolved oxygen through decomposition when they die (US-EPA 2009).

Trace metal concentrations in water

The metal and metalloid concentrations were compared with national and international limits for drinking water (SANS, 2002, 2006; WHO, 2011; USEPA, 2009) (Table 3.4). The higher spatial variation of the trace metal(loid) concentrations exhibited in the rivers is attributed to runoff from the various activities in their basins (Addo-Bediako, 2020). Most of the metal(loid) concentrations in the rivers were very low and this could be due to the fact that in aquatic ecosystems, most metals are deposited in the associated sediments (Fabio et al., 2021; Awadh et al., 2021; Herath et al., 2018). Thus, sediments act as a reservoir of contaminants and are potential secondary sources of contaminants in the aquatic system (Islam et al., 2015, Addo-Bediako et al., 2021). The highest concentrations of trace metal(loid)s were recorded mainly at the lower reaches of the rivers due to discharges received from the catchments.

The concentration of Mn exceeded SANS, WHO and USEPA water quality guidelines for drinking water, at almost all the reaches of the three rivers. The relatively high concentration of Mn could be attributed to increasing anthropogenic discharges during rainfall (Zhang et al., 2021). In the Letaba River, it could come from fertilisers applied in the agricultural fields. The high Mn concentration could have adverse effects on organisms in the rivers. The concentrations of the rest of the metal(loid)s were mostly below the recommended values (Table 3.4), however, it is important to note that sediments can trap trace metals during hydrological cycles (Alahabadi and Malvandi, 2018), and can be re-released into the water, resulting in secondary pollution with changes in physicochemical conditions in the sediments (Kim et al., 2021; Shu et al., 2021).

Table 3.4: Maximum permitted trace metal concentrations (mg/L) for drinking water quality and protection of freshwater aquatic life.

Water quality	As	Cd	Cr	Co	Mn	Ni	Pb	Zn
SANS (2015)			0.05	-	0.04		0.01	5.0
EU (1995)	0.01	0.005	0.05	-	0.05	0.02	0.01	0.1
WHO (2006, 2011)	0.01	0.003	0.05	-	0.40	0.07	0.01	2.0
USEPA (2009)	0.01	0.005	0.05	-	0.05		0.015	5.0

3.6 Conclusion

The study shows variations in the spatial distribution of trace metal(loid)s in the water of the Groot Letaba, Keiskamma and Mthatha rivers. This was due to different distribution characteristics caused by human activities (e.g. industrial, agricultural, domestic) in the basins. The concentrations of the elements assessed were within the SANS, WHO and USEPA water quality guideline values for drinking water at some sites. However, the concentrations of Mn exceeded the drinking water guidelines in the three rivers. The high concentration of Mn might be related to the effluents from human activities especially fertilisers in the Groot Letaba River. Generally, most of the elements in the water do not pose any immediate human health risk, as the levels are below the international permissible standard levels. However, it is necessary to develop a long-term monitoring scheme to assess the levels of trace metals in the basins, due to the increasing human activities in their catchments. It is recommended that future studies of water quality should include sediment quality as sediments can trap trace metals during hydrological cycles, but if there are changes in physicochemical conditions in the sediments, trace metals can be re-released into the water, resulting in secondary pollution of the aquatic environment.

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Chapter 4: Assessing the effect of Land Use and Land Cover Change on soil CO_2 emission in Limpopo and Eastern Cape catchments

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4.1 Abstract

Carbon dioxide (CO_2) is the most important greenhouse gas accounting for 60% of the total greenhouse effect. Its continuous release has led to a constant increase in global warming. Land use type and land cover have a significant impact on soil carbon dynamics and it is known that land use change is one the main drivers of CO_2 emission in agricultural systems. Even though most CO_2 emissions are from the burning of fossil fuels, agriculture contributes significantly. Thus, the main objective of this study was to determine the impact of land use and land cover changes on the soil organic carbon stocks, soil CO_2 emission, hydraulics and other physical soil properties. To achieve the objective soil CO_2 emission rates were measured every two weeks for a whole year in the Letaba catchment while some measurements were also done in the Keiskamma catchment. Nine land use systems were studied in the Letaba catchment and three in the Keiskamma catchment.

The findings of the study in the Letaba catchment showed that several soil chemical properties varied among the land use systems. Notable differences were observed in the amount of phosphorus which is attributed to the management practices where higher amounts were observed in fertilised orchards compared to the natural systems. Soil physical properties also varied among the land use systems. It was observed that the amount of carbon stocks stored in the forest (thicket) (1.19 kg/m^2) was more than 5 times higher than the amount of carbon stored in land use systems such as the bush and citrus orchards (0.23 kg/m^2). The higher carbon stocks in the forest are attributed to mainly higher litter fall and reduced soil temperatures. Soil CO_2 emission rates varied with both season and land use systems in the Letaba Catchment. It was observed that soil CO_2 emission rates were mostly higher in the autumn and summer seasons compared to the spring and winter seasons. Higher emission rates in summer were mainly because of the combination of higher moisture availability and warmer temperatures which promote microbial activity. In winter emissions were lower mainly due to the lower temperatures experienced in the season. It was also observed that soil CO_2 emission rates from the different land use systems varied but were dependent on the systems. For example, emission rates were higher in forests during the

summer season while higher rates were observed in irrigated systems (i.e. citrus) in the winter seasons.

In the Keiskamma catchment, soil CO_2 emission varied with the land use type and the location. It was observed that on average grasslands released more soil CO_2 compared to croplands and grazing lands. This could be attributed to higher autotrophic and heterotrophic respiration in grasslands during the period when measurements were taken. In terms of location, it was observed that the Blinkwater Village had significantly higher emission rates compared to the Mbizana village but did not vary with the Ncerha village. Variations among the three different land use systems were also observed in each of the three locations studied.

In conclusion, the findings of the study show that the amount of CO_2 released into the atmosphere varies with land use type and that seasons play a significant role in the emission rates due to the influence of soil moisture and temperature.

From the findings of this study, high frequent measurements of soil CO_2 emission rates are recommended to fully understand the temporal variation of soil CO_2 emission in the different land use systems. To fully understand the major drivers of soil CO_2 emissions in these different land-use systems, other factors such as the microbial decomposer communities and the aggregate-associated carbon need to be considered. Finally, it is recommended that soil carbon stocks be determined at a higher spatial resolution to completely document the amount of soil carbon stored in the soils and this should be done to a greater depth of the soil profile.

4.2 Aim of the report

This chapter reports on the impact of land use and land cover changes on soil CO_2 emission in the Letaba and Keiskamma river catchments. This report follows the identification of the different land use and the land cover as reported in Chapter 1: "Land Use and Land Cover Change characterization in three catchments in South Africa". This chapter focuses on the CO_2 emission in the Letaba catchment, Limpopo Province and Keiskamma catchment, Eastern Cape Province.

4.3 Background

Global warming and climate change are great concerns requiring exhaustive research on CO_2 emission from soil under different land use and management options (Rahman, 2013). Carbon dioxide (CO_2) is the most important greenhouse gas accounting for 60% of the total greenhouse effect (Rastogi et al., 2002; Brander and Davis, 2012). Its continuous release has led to a constant increase in climate change. It is reported that CO_2 concentration in the atmosphere has been increasing at a rate of 3.2 x 10^{15} g C $year^{-1}$ of which 20% comes from soil respiration (Rastogi et al., 2002). This has seen CO_2 concentration increasing from 280 ppmv at the beginning of the industrial revolution to more than 400 ppmv in the present day. It is therefore critical to curtail its emission into the atmosphere and arrest the ever-changing climate. This can be done by identifying land-use systems that sequester carbon.

Land use type and land cover have a significant impact on soil carbon dynamics (Toru and Kibret, 2019). Also, the level of disturbance in the soil has an impact on CO_2 emission and carbon storage (Toru and Kibret, 2019). Carbon storage is enhanced where there are fewer disturbances, thus less disturbed soils accumulate more soil organic carbon (Anokye et al., 2021). Thus cultivated lands would normally have low organic carbon compared to undisturbed lands like forests and grasslands especially when no appropriate measures are taken to conserve the organic carbon (Tolimir et al., 2020). Land use change, particularly the conversion of natural systems into managed systems, results in the alteration of the carbon balance (Toru and Kibret, 2019). The conversion of forests or grasslands to cultivated lands causes a reduction in the soil organic carbon levels (Tolimir et al., 2020). Cultivation usually involves tillage which leads to the breakdown of residues and hastens the oxidation process which results in the loss of carbon through CO_2 (Yu et al., 2020). The organic carbon in the forest can be attributable to the relatively lower soil temperatures due to the shading that then results in reduced decomposition rates (Anokye et al., 2021, Rajput et al., 2017).

The decomposition of soil organic matter and CO_2 release is influenced mainly by soil moisture and temperature (Rastogi et al., 2002). High soil temperature and moisture content promote increased microbial activity, and sufficient organic material results in higher decomposition rates and the emission of CO_2 into the atmosphere (Dhital et al., 2014). Other factors that influence CO_2 emission from the soil are soil texture, soil pH, tillage, and fertiliser application among others (Rastogi et al., 2002, Oertel et al., 2016). Overall, carbon emission and storage from soils are influenced by both edaphic and management practices.

The main aim of this study is to determine soil carbon storage and CO_2 emission rates in different land use systems of the Letaba, Keiskamma and Mthatha catchments. However, this report will focus on the CO_2 emission in the Letaba catchment, Limpopo Province and the Keiskamma catchment, Eastern Cape province. The report will concentrate on CO_2 emission rates in nine land uses in the Letaba and three land use systems in the Keiskamma.

4.4 Study area description

4.4.1 Letaba River Catchment

The Letaba River catchment is located between longitudes 30°0′ and 31°40′ East and latitudes 23°30′ and 24°0′ South, in the Mopani District of Limpopo Province, South Africa (**Figure 4.1**). The Letaba River catchment has a surface area of 67,000 km^2. The full description of the study area is well described in the Chapter 1 report entitled: Land Use and Land Cover Change characterization in three catchments in South Africa submitted to the WRC report under project C2019/2020-00166. In the report, several land use and land cover maps were produced. Figure 4.1 shows the land use and land cover map for the year 2020. Several broader land uses were identified which include cultivated lands, grasslands, natural forests, plantations, and shrublands among others. A total of nine land uses were then selected for the measurement of CO_2. These were avocado orchard, citrus orchard, banana plantation, *Eucalyptus grandis* plantation, wooded forests, open bushland, bushland, a thicket forest and communal maize fields (Figure 4.2). These land uses systems were selected because they are the most dominant with the largest spatial distribution in the catchment.

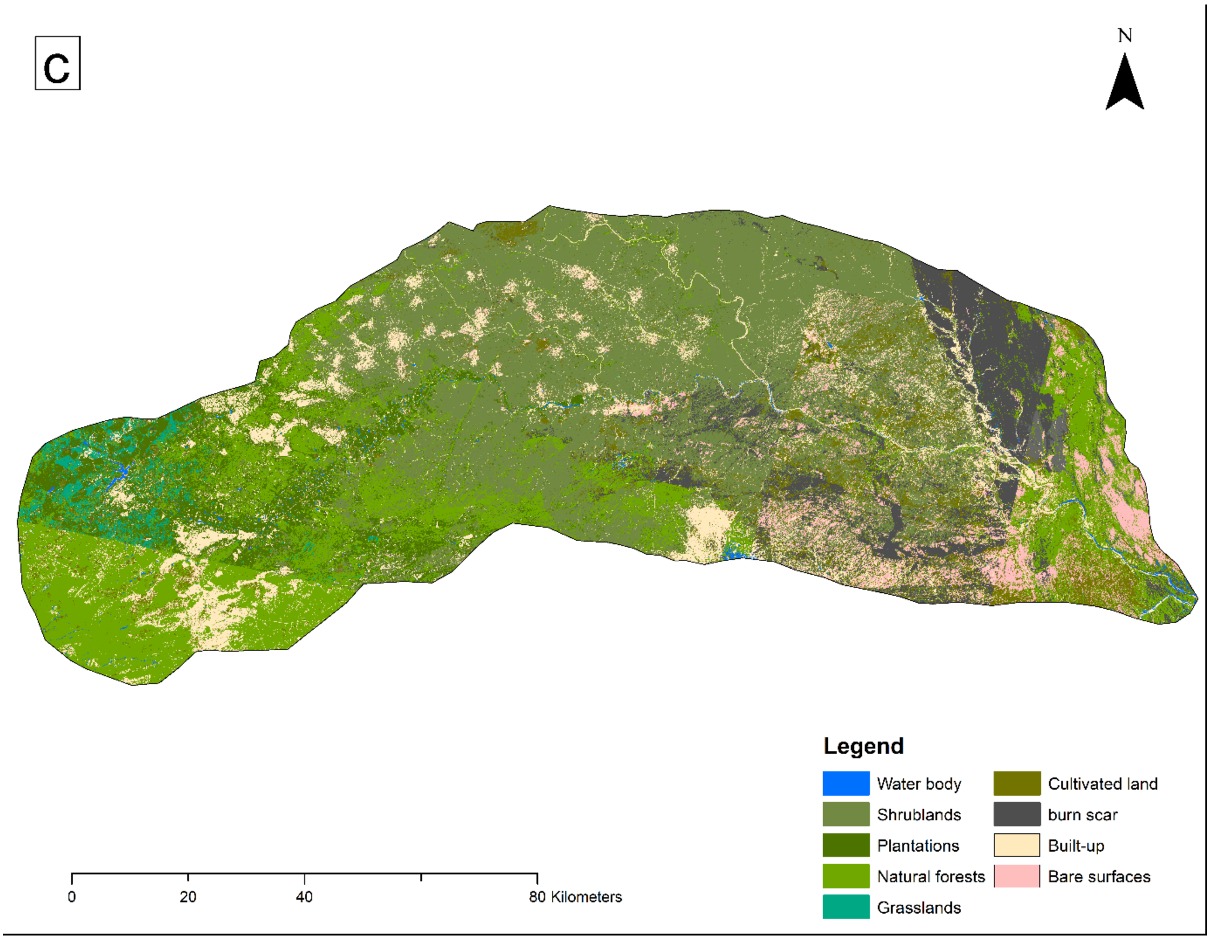


Figure 4.1: Land cover and land use map for Letaba catchment Limpopo Province

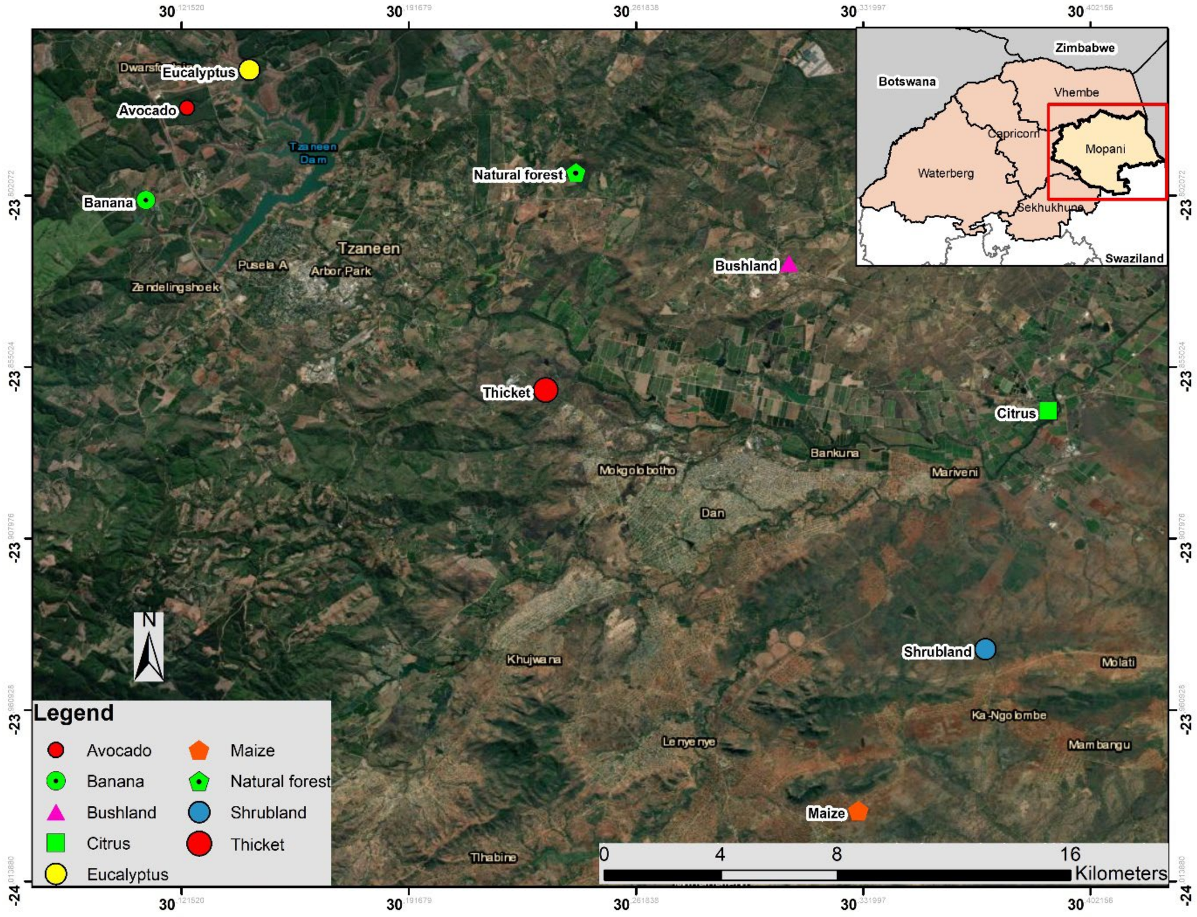


Figure 4.2: Location of the different land use systems identified in the Letaba catchment for CO_2 emission data.

4.4.2 Keiskamma River Catchment

The Keiskamma is one of the largest catchments in the semi-arid region of the Eastern Cape Province of South Africa, covering an area of 2 745 km² which forms approximately 35% of the former Ciskei region (Hill, 1991) (**Figure 4.2**). The Keiskamma river is the main river in the catchment with headwaters situated in the Amatole Mountains above Keiskammahoek town and flows eastwards for 263 km and drains into the Indian Ocean at the resort town of Hamburg (33°17´S 27°29´E). The main tributaries of the Keiskamma River are Tyume, Chalumna and Gulu, with the Tyume headwaters in Hogsback (DWAF, 2004). Similar to the Letaba catchment, the full description of the land uses is provided in the report submitted to the WRC. Figure 4.3 shows the different major land uses that were identified in the Keiskamma which included agricultural land, bare land, natural vegetation among others. The following land uses were then selected: Grassland, croplands and grazing lands.

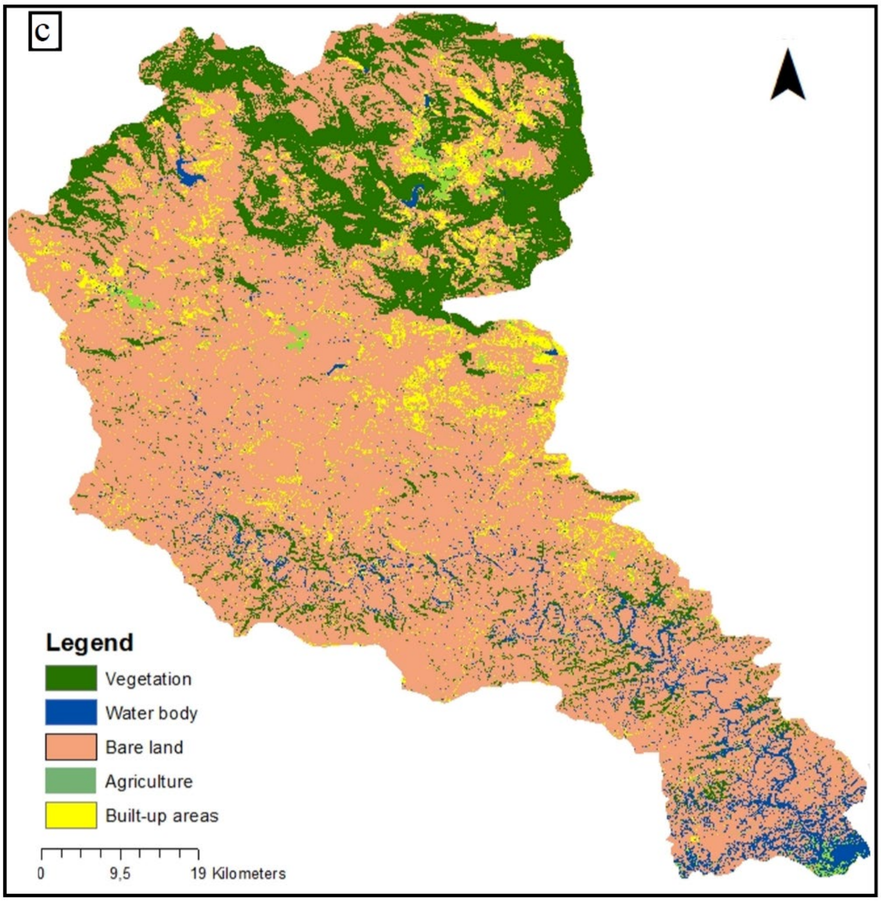


Figure 4.3: Land cover and land use map for Keiskamma catchment, Eastern Cape Province.

4.5 Material and Methods

4.5.1 Field data collection for Letaba Catchment

4.5.1.1 Soil CO_2 emission rates

Soil CO_2 emission rates in the Letaba catchment were measured using the static chamber system as shown in Figure 4.4.

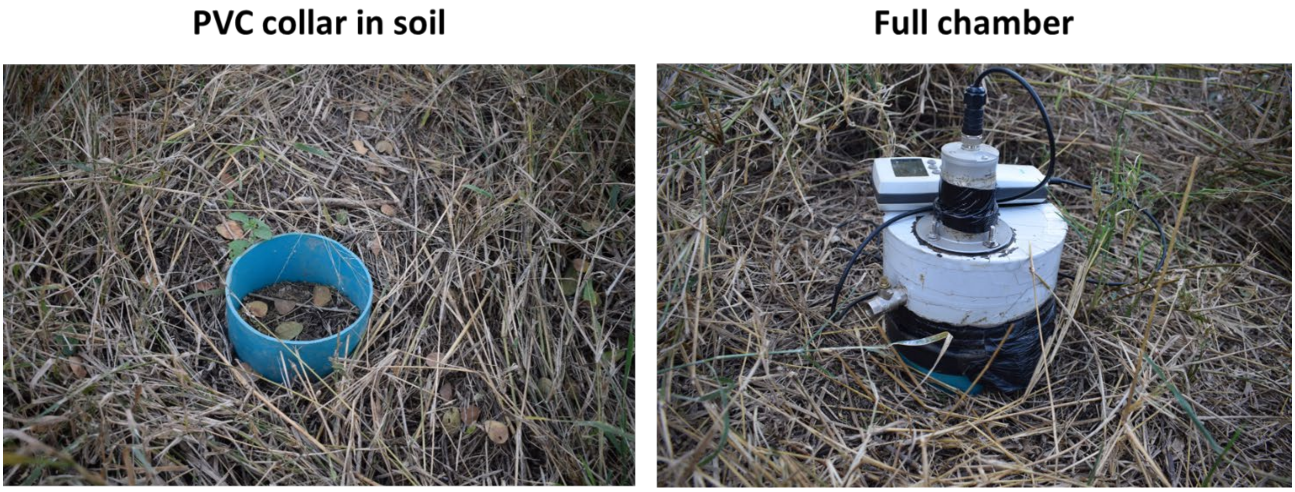


Figure 4.4: Chamber system used for CO_2 measurement in the Letaba catchment

In each of the selected nine land use systems three 20 x 20 m plots were randomly selected and the chamber collars were installed in each. However, for commercially grown orchards and plantations, i.e. avocado, banana and citrus, the chambers were installed about 1 m from the tree trunk and one chamber in the middle of separate rows. The inter-row spacing for orchards is on average about 6 m with an in-row spacing of about 2.5 m. Carbon dioxide concentration was then measured every 5 seconds for 5 minutes per spot using the GMP3 CO_2 probe (Vaisala, Germany). The measurements were taken every two weeks. For this report, the results reported are from March to October 2021, however, the measurements will continue until a full year is completed. All measurements were done between 10h00 and 14h00.

4.5.1.2 Calculation of CO_2 fluxes

The CO_2 probe GMP343 gives measurements of CO_2 in parts per million (ppm). The measurements were first converted to mg m^{-3} using equation 1(Collier et al., 2014).

$$CO_2\ (\text{mg m}^{-3}) = \left(\frac{CO_2 ppm\ x\ Molar\ weight\ (CO_2)}{22.4 Lmol^{-1}}\right) x \left(\frac{273.15K}{T\ (K)}\right) x \left(\frac{P(kPa)}{101kPa}\right) \quad (1)$$

Where CO_2 ppm is the measured concentration of CO_2 at any given time, T is the chamber temperature (Temperature in °C + 273.15 K) and P is the ambient pressure.

CO_2 concentration in mg m^{-3} was then plotted against time (min) giving a slope in mg m^{-3} min^{-1}. The slope of the resulting regression lines was then determined for each installed chamber, with a coefficient of variation values (R^2). The slope was then multiplied by the volume of the chamber and divided by the area covered by the chamber giving the resultant flux in mg m^{-2} min^{-1}, which describes the CO_2 flux out of the soil.

Cumulative CO_2 was calculated by taking an average rate between two measurement points and multiplying it by the time between the two points.

4.5.1.3 Soil Moisture and temperature

Soil moisture was measured using a portable soil moisture sensor SM150T, measuring soil moisture in the top 5 cm of the soil profile. The soil temperature, i.e. surface soil temperature was inferred from the temperature recorded in the chamber.

4.5.2 Field data collection for Keiskamma Catchment

4.5.2.1 Soil CO_2 emission rates

Soil CO_2 emission rates in the Keiskamma catchment, Eastern Cape were measured using LI-COR 8100A as Shown in Figure 4.5. Chamber anchors of the equipment are installed to a depth of 10 cm into the soil and extended to no more than 5 cm above the surface. The LI-COR 8100A allows for the measurement of both CO_2 flux and soil temperature. The measurements were carried out every two weeks in September 2021 and continued every two weeks until December 2022. Carbon dioxide flux, soil moisture, and temperature measurements were taken between 9 am and 12 pm to minimise the diurnal variation in gas measurement and to reflect the mean daily temperature.

LICOR 8100 chambers

Figure 4.5: Setting up of the Li-Cor 8100 chambers for the measurement of CO_2 emission rates at Ncerha village in the Eastern Cape.

4.5.2.2 Soil Moisture and temperature

Soil moisture in the top 20 cm was measured by using a Hydro Sense II moisture probe (Campbell Scientific, Inc. Logan, Utah, UT 84321-1784, USA). The temperature was also measured through a soil moisture sensor connected to the LI-COR 8100A system. The soil temperature was measured in the top 5 cm of the soil.

4.6 Results

4.6.1 Letaba catchment

4.6.1.1 Soil chemical Properties, organic carbon and total nitrogen

The chemical properties of the soil in the different land use systems are shown in Table 4.1. The results showed that the amount of phosphorus (P) did not significantly differ among the land use systems. However, it was clear that higher amounts of P in avocado and citrus orchards compared to for example bushes, forest and eucalyptus. The basic cations of Potassium (K), Calcium (Ca), and Magnesium (Mg) also showed variations among the land use systems. Potassium was significantly higher in avocado and banana orchards compared to the other land use systems while Ca and Mg were higher in the bush.

Zinc did not vary among the land use systems but was relatively higher in the avocado, bush (open) and citrus. Manganese (Mn) was highest in the maize field with 43.24 mg/kg compared to the other land use systems. The lowest amount though not significant to some was observed in the citrus with 11.97 mg/kg. Copper (Cu) as well showed significant variations among the different land use systems. It was highest in avocado (18.24 mg/kg). Differences in Cu were also observed between citrus (6.11 mg/kg) and bush (wetland) (1.25 mg/kg).

Organic carbon (OC) and N% also showed differences among the different land use systems. Forest thickest had an OC percentage of 1.93% which was about 4 times higher than the amount of OC in the bush(open) and citrus. On the other hand, total N was observed to be highest in the avocado orchard which was also about 5 times higher than observed in the bush (open) and citrus. Generally, both OC and N were relatively low in all the land use systems.

Table 4.1: Chemical properties of soils in the different land use systems around the Letaba catchment

Landuse	P(mg/kg)	K(mg/kg)	Ca(mg/kg)	Mg(mg/kg)	pH (KCL)	Zn(mg/kg)	Mn(mg/kg)	Cu(mg/kg)	Org, C (%)	N (%)
Avocado	64.27	241.87a	884.85abc	176.78c	5.04bc	35.89	19.10bc	18.24a	0.97ab	0.26a
Banana	61.07	213.96a	631.58bc	117.97c	4.55c	6.38	33.75ab	5.19bc	0.90ab	0.07c
Bush (wetland)	1.25	80.25c	385.64c	129.44c	4.85bc	0.37	16.46bc	1.25c	0.80ab	0.07c
Bush(open)	5.35	53.18c	1643.53a	484.54a	5.12bc	11.36	22.30bc	3.26bc	0.50b	0.05c
Citrus(orange)	12.23	102.77bc	755.09abc	163.75c	7.54a	22.31	11.97c	6.11b	0.50b	0.05c
Eucalyptus	4.02	65.89c	1305.35abc	199.29c	6.02b	0.64	27.51bc	2.17bc	1.10ab	0.17ab
Forest	4.11	151.98abc	1253.34abc	219.76bc	5.65bc	2.07	21.91bc	1.77bc	1.50ab	0.08c
Forest(thicket)	14.95	68.44c	1362.47ab	327.66b	5.11bc	1.20	15.17c	5.67bc	1.93a	0.10bc
Maize field	13.73	208.01ab	947.66abc	210.81bc	6.02b	9.10	43.24a	5.67bc	0.53b	0.05c
	ns	***	**	***	***	ns	***	***	*	***

4.6.1.2 Soil physical properties

Soil physical properties such as the bulk density of soil, soil carbon stocks, aggregate stability, infiltration rates and clay content were determined to understand the impact of land use on these parameters (Figure 4.6). The results showed that bulk density varied with the land use system (Figure 4.6). Bulk density was significantly lower in the forest and citrus orchards compared to the other land use systems. Soil carbon stocks also varied with land use systems. It was observed that the amount of carbon stocks stored in the forest (thicket) (1.19 kg/m^2) was more than 5 times higher than the amount of carbon stored in bush2 and citrus orchards (0.23 kg/m^2).

The stability of soil aggregates in the different land use systems was also found not to be the same. It was found that the mean weight diameter of the aggregates in the citrus, maize field and banana were significantly lower than those in other land use systems. Bush1 and Bush 2 were among the land use systems with higher MWD. The MWD of all land use systems ranged from 0.68 to 1.88. Infiltration rates on the other hand did not show much significant variations. Bush1 had the highest and extremely high infiltration rate of 49.9 mm/h followed by maize field (19.02 mm/h) and then the bush2 13.27 mm/h). The other land use systems had infiltration rates of below 6 mm/h.

The clay content in the different land use systems differed significantly. The clay content was significantly higher in the avocado plantation at 57.7% followed by banana with 41.7% which did not differ from eucalyptus (38%). The other land use systems did not differ from each other but the lowest clay content was recorded in the bush1 with only 10.3%.

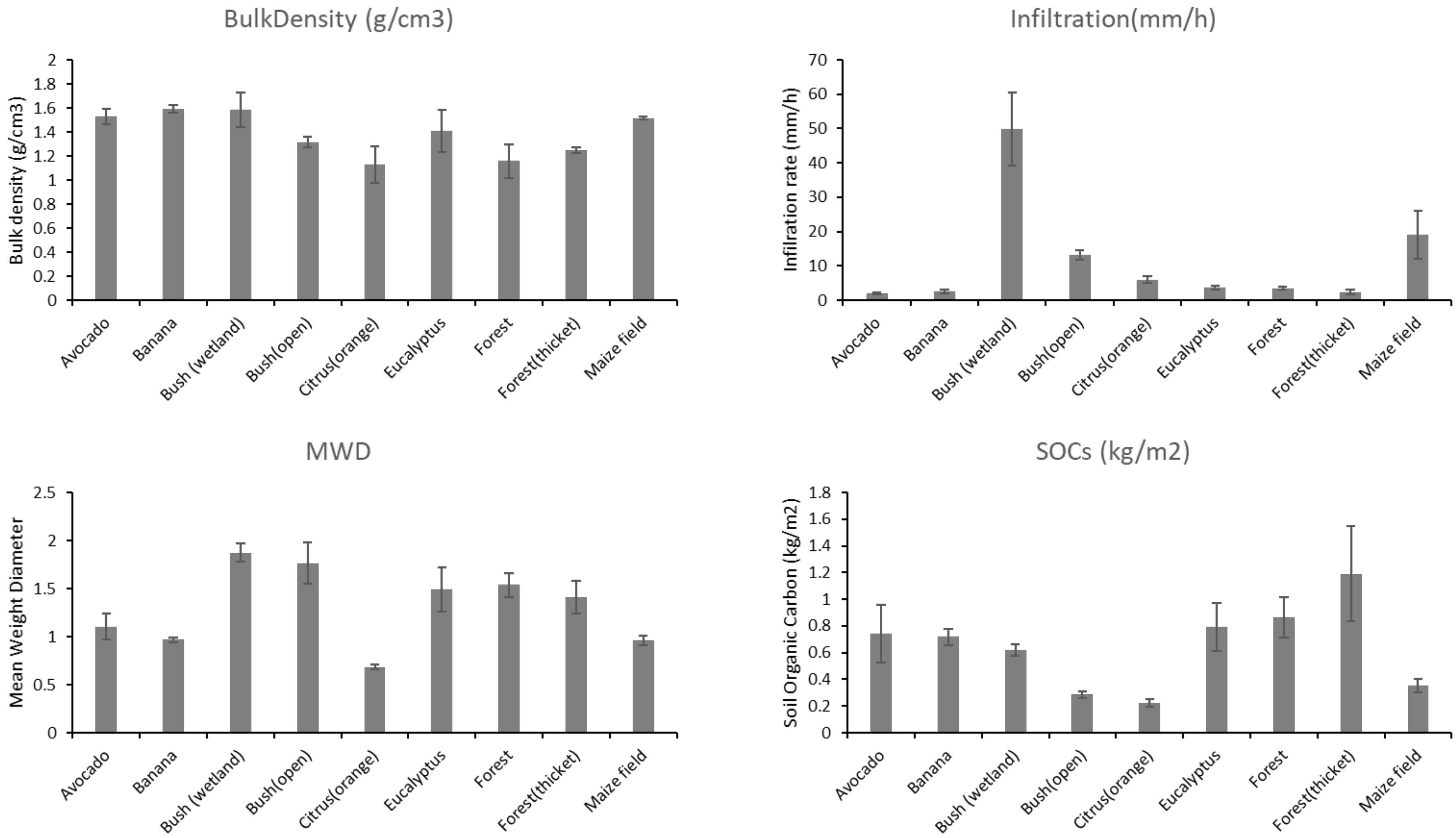


Figure 4.6: Soil physical properties in the nine land use systems around the Letaba catchment

4.6.1.3 The Soil CO_2 emission rates

The results show that soil CO_2 emission rates in all the studied land use systems in the Letaba catchment followed a similar trend in how they varied with time (Figure 4.7). The CO_2 emission rates were relatively higher in the autumn months and then decreased in winter. The soil CO_2 emission rates remained low into the spring season for land use systems whose soil moisture relies on rainfall that is maize field, eucalyptus plantation, forests and bushlands. However, for irrigated plantations and orchards (banana, avocado and citrus), the soil CO_2 emission rates started to increase into the spring season as the temperatures started to rise. This trend was most noticeable in citrus. For land use systems that rely on rainfall, the soil CO_2 emission rates remained low due to lack of moisture.

Significant differences in the soil CO_2 emission rates were found between the land use systems at different measurement dates. In the autumn season higher soil CO_2 emission rates were observed in the thicket and banana and lower in the maize field, wooded forest and open bush. The emission rate in the thicket was 77% higher than observed in maize at the beginning of autumn (Table 4.2). However, the difference reduced towards the end of autumn into the winter season. In the winter season CO_2 emission rates were significantly higher in the citrus and banana compared to eucalyptus and open bush and maize field. Citrus soil CO_2 emission rate around mid-June and mid-July was more than twice as high as that recorded under maize field. In the Spring season, the emission rates in citrus were more than eight times higher than the rates observed in the maize field.

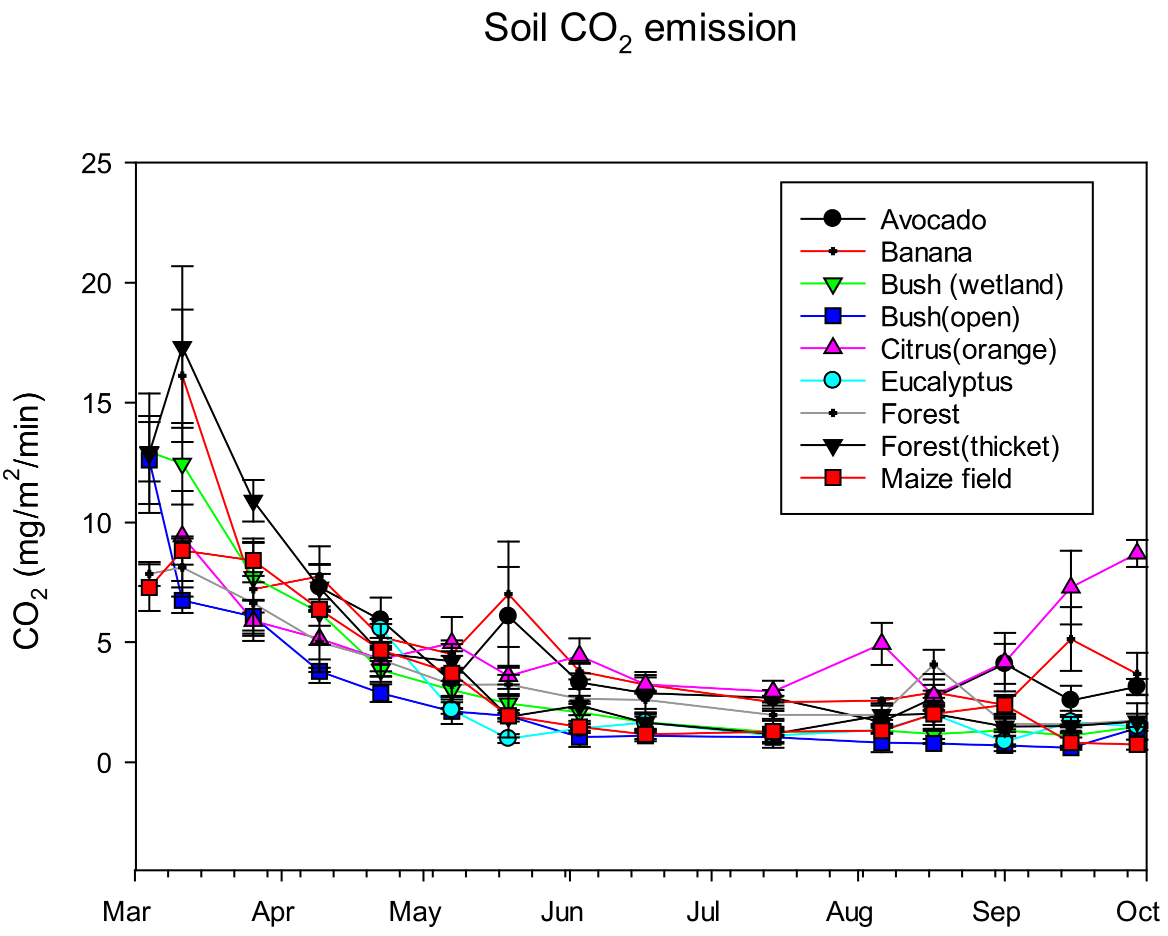


Figure 4.7: Variation of soil CO_2 emission rates in different land use systems with time

Table 4.2: Mean CO_2 emission rate values (mg/m^2/min) from different land use systems in the Letaba catchment measured at different dates.

Land Use	04/03/2021	11/03/2021	26/03/2021	09/04/2021	22/04/2021	07/05/2021	19/05/2021	03/06/2021	17/06/2021	14/07/2021	06/08/2021	17/08/2021	01/09/2021	15/09/2021	29/09/2021
Avocado				7.29	5.93	3.35	6.08	3.32	2.88	2.69	1.68	2.69	4.10	2.58	3.15
Banana	-	16.12	7.22	7.75	5.22	4.51	7.01	3.79	3.23	2.50	2.56	2.91	2.39	5.13	3.68
Bush 1	12.95	12.45	7.71	6.24	3.84	3.01	2.45	2.08	1.67	1.25	1.33	1.18	1.33	1.11	1.48
Bush 2	12.61	6.75	6.07	3.79	2.88	2.12	1.93	1.05	1.10	1.04	0.82	0.78	0.70	0.61	1.42
Citrus	-	9.43	5.90	5.15	4.30	5.0	3.59	4.44	3.24	2.94	4.93	2.77	4.17	7.29	8.71
Eucalyp	-	-	-	-	5.57	2.18	0.98	1.40	1.66	1.11	1.35	2.00	0.86	1.68	1.49
Forest1	7.85	8.12	6.63	5.01	4.28	3.23	3.24	2.65	2.60	1.97	1.97	4.07	1.60	1.58	1.74
Thicket	12.89	17.32	10.91	7.28	4.54	4.21	1.90	2.36	1.65	1.18	1.96	2.02	1.49	1.50	1.70
Maize	7.28	8.83	8.42	6.37	4.67	3.72	1.93	1.47	1.16	1.28	1.31	2.01	2.39	0.82	0.74

Bush 1 is an open bush labelled bush (wetland) in other graphs; bush 2 is shrub land (labelled as bush open); forest 1 is a wooded forest and thicket is forest thicket.

4.6.1.4 Cumulative CO_2

The cumulative amount of CO_2 released in the different land use systems is presented in Figure 4.8, showing the total amount of CO_2 released in each land use system from the first day of measurement. The results show that from early march until the end of September citrus orchard and banana plantations have released the highest amount of CO_2 into the atmosphere at 14.15 and 14.58 tons/ha respectively. The total amount of CO_2 released in citrus was 110% higher than that released from the open bush, 60% higher than that released from the maize field, and more than 200% of that in *Eucalyptus*. However, the CO_2 emission rates in *Eucalyptus* were recorded more than a month later from the citrus. It is also interesting to note that in the autumn season, the thicket released more CO_2 than any other land use system but was overtaken by banana in the winter and then again by citrus at the beginning of spring. A similar trend was also observed between avocado and maize field. However, no differences were observed between the cumulative rates of wooded forest, bush and maize.

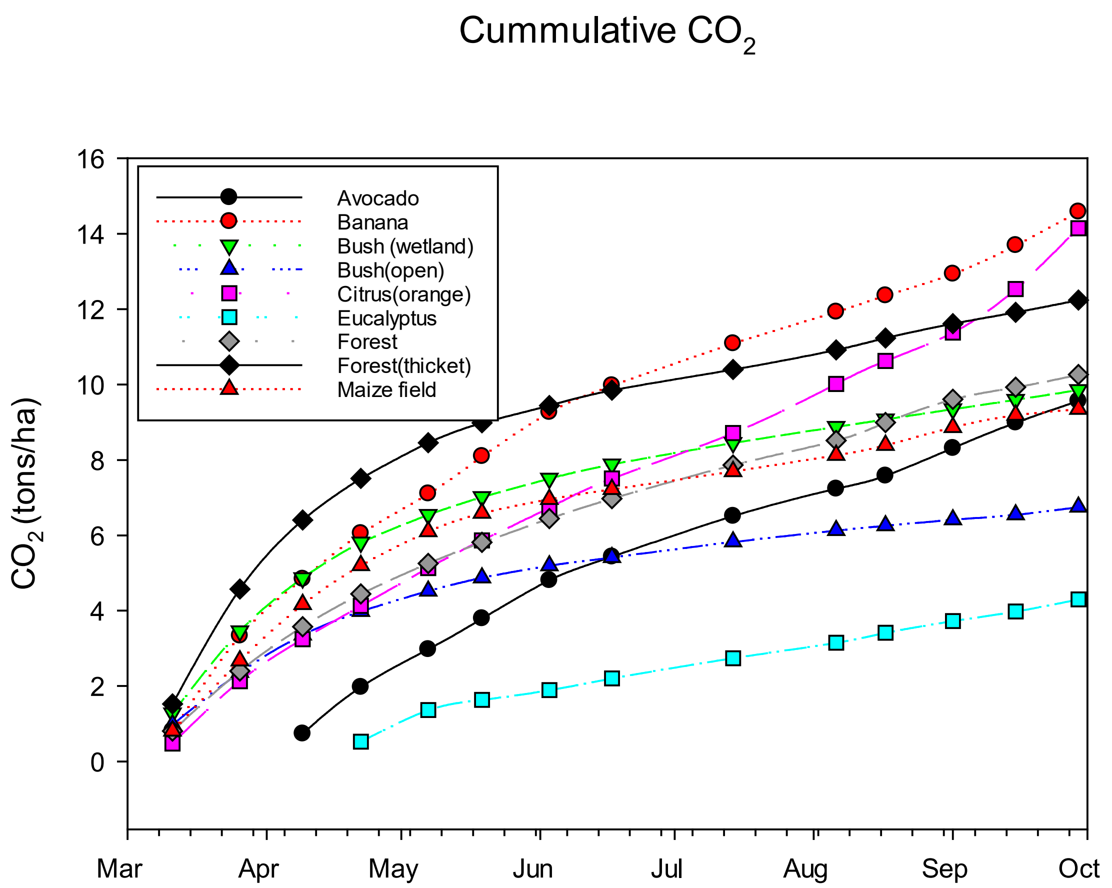


Figure 4.8: Cumulative CO_2 in different land use systems of Letaba

4.6.1.5 Soil Moisture

Soil moisture also varied with land use system. At the beginning of March higher soil moisture levels were recorded in the banana plantation and the wooded forest and were significantly higher than in maize field and all bushlands (Figure 4.8). Moisture in the banana averaged around 33% while it was below 10% for the maize field. Soil moisture in the non-irrigated land use systems showed a decreased trend of soil moisture with time from autumn to spring. From the winter to spring, soil moisture in the maize field, bushlands, and forest averaged below 5%. Avocado orchards maintained higher moisture levels throughout the study period with an average of 30% and were significantly higher than all other land uses except for citrus in early September. Generally, irrigated orchards and plantations (avocado, citrus and banana maintained higher moisture levels as expected. Eucalyptus also had relatively higher moisture levels due to the higher mulching provided by the leaves.

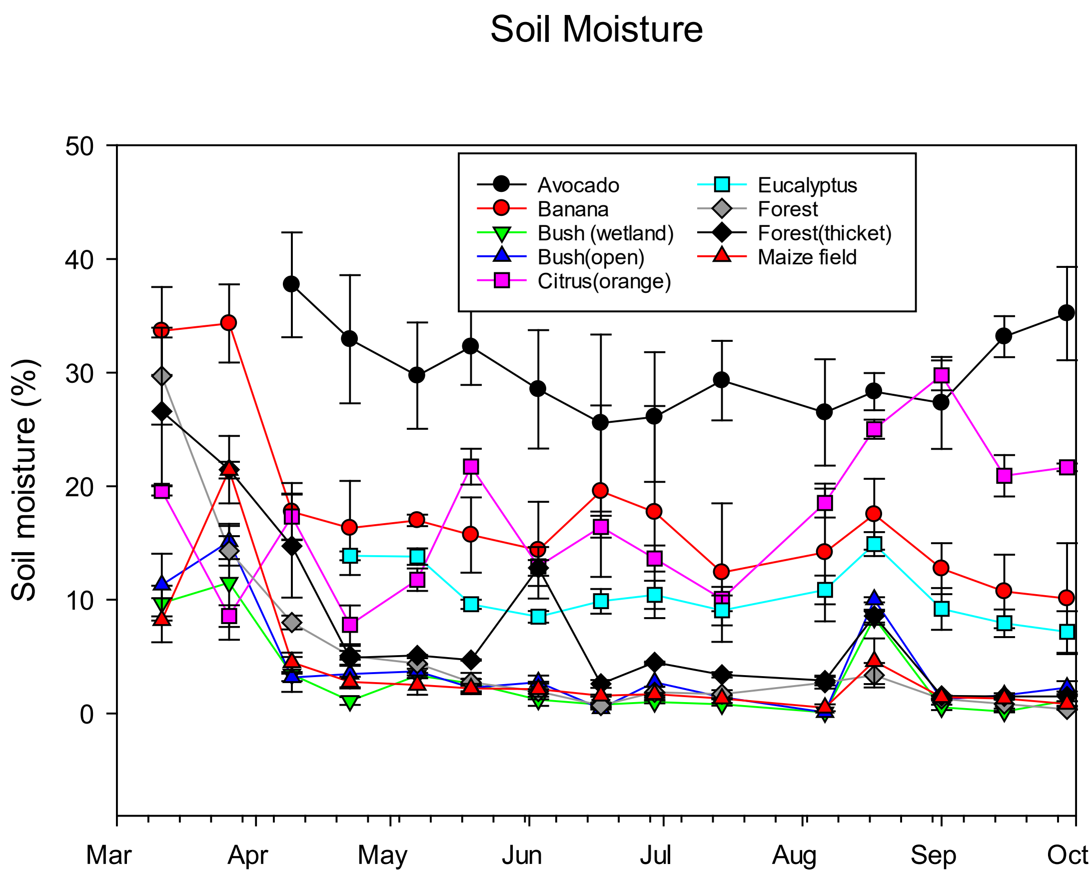


Figure 4.9: Soil moisture in nine land use systems in the Letaba.

4.6.1.6 Temperature

Soil surface temperatures were inferred from the chamber temperatures and are shown in Figure 4.9. Significant differences in the soil surface temperatures were observed throughout the study period. In the autumn season, significantly higher soil surface temperatures were recorded in bushlands and maize compared to thicket and banana. Temperatures in the banana plantation, *Eucalyptus* and avocado remained lower compared to other land uses.

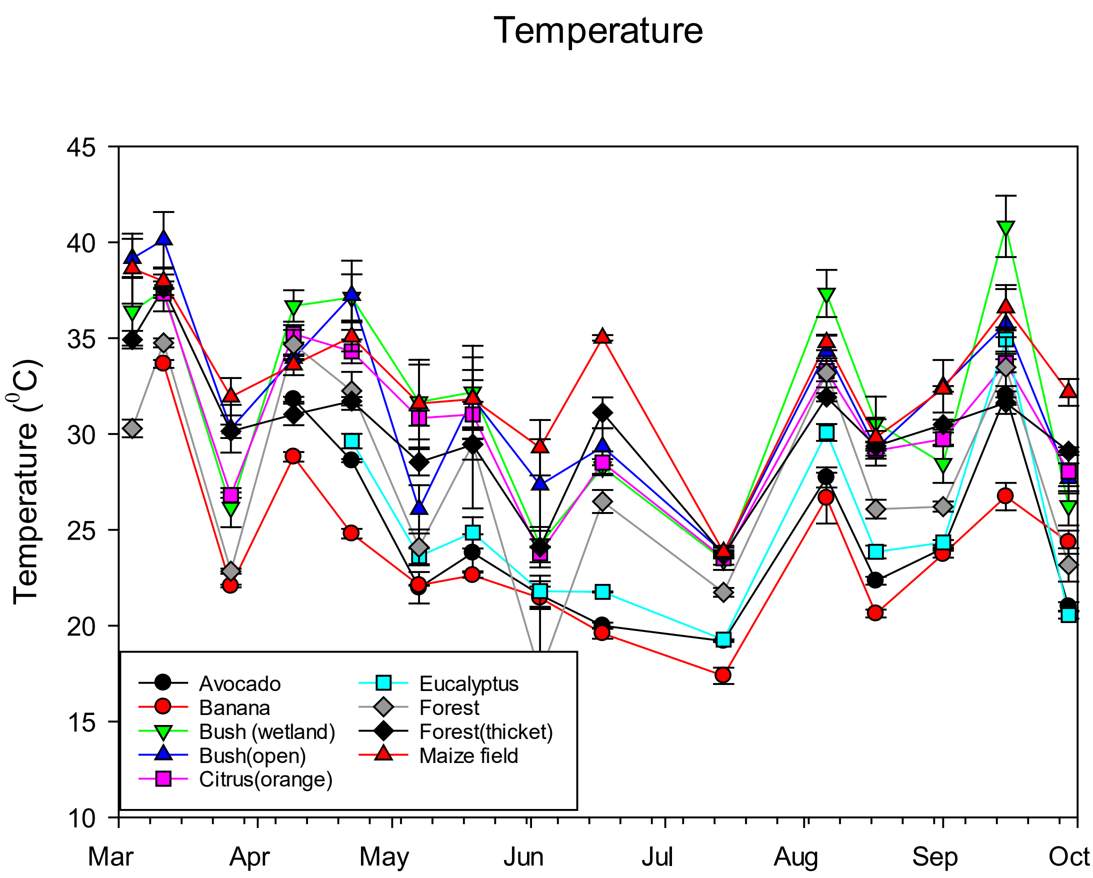
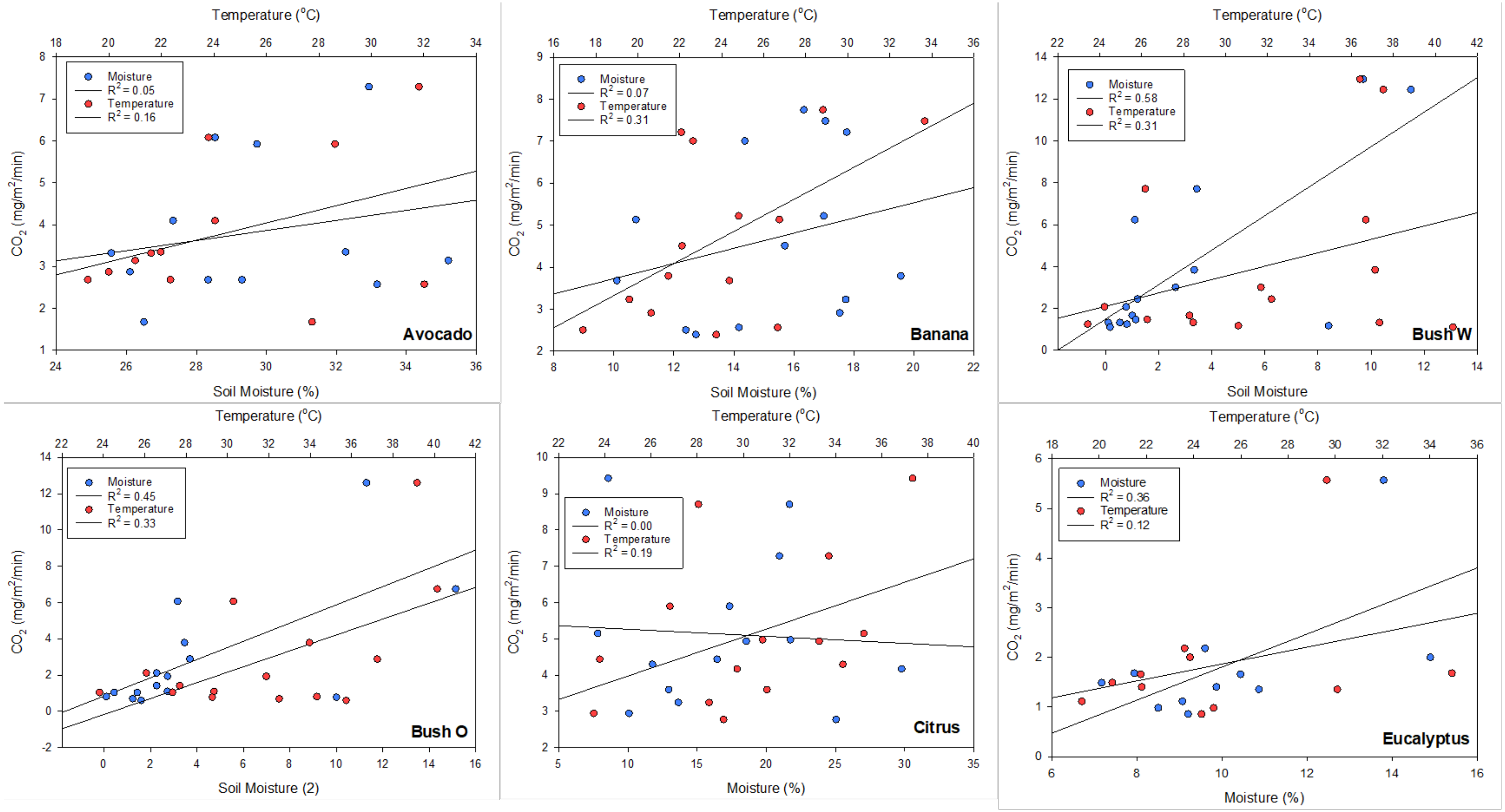


Figure 4.10: Chamber temperature measured in the nine land use systems in the Letaba catchment.

4.6.1.7 Relationships between soil CO_2 emission rates, soil moisture and soil surface temperature

The regression analysis of CO_2 emission rates and moisture content as we as temperature are shown in Figure 4.10. The results show that there was generally a positive relation between CO_2 emission rates and both soil moisture and temperature. The relationships, however, were generally weak for most land uses. It was also noted that stronger positive relationships were observed with soil moisture for land uses that rely on rainfall. For land use systems that are irrigated, i.e. banana, avocado and citrus, relatively weaker positive relationships of CO_2 with temperature was observed but the relationship was mostly non-existent with soil moisture. For irrigated land use systems, the trend was more pronounced in citrus.



Avocado
Banana
Bush W
Bush O
Citrus
Eucalyptus
Temperature (°C)
Soil Moisture (%)
Soil Moisture
Soil Moisture (2)
Moisture (%)
CO2 (mg/m2/min)
Moisture
Temperature

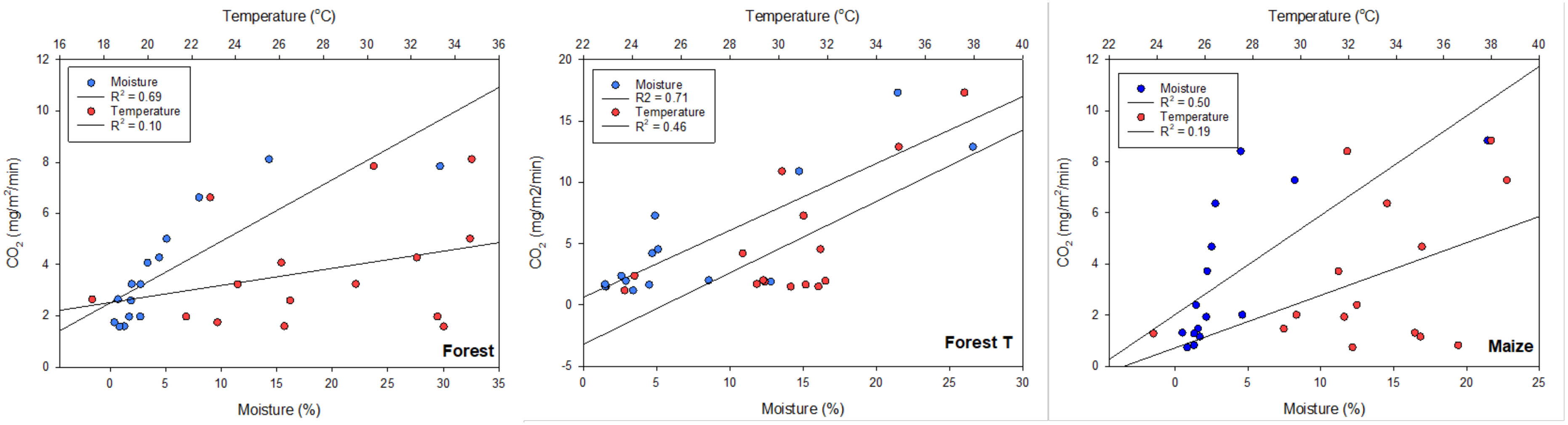


Figure 4.11: The relationship between CO_2 emission rates, moisture, and temperature.

4.6.2 Keiskamma Catchment

Soil CO_2 emission was measured in three villages and three land use systems in the Keiskamma catchment. The results showed a significant variation in soil CO_2 emission in between villages where higher CO_2 emission rates were observed in the Drinkwater village which has a sub-humid climate compared to Mbizana which is arid with shallow soils (Figure 4.11). Soil CO_2 emission from the same-arid Ncerha village was not different from the other villages. Variation in land use systems was also observed with grassland having higher soil CO_2 emission rates than cropland, but similar to grazing land. An average of 2.01 mg/m^2 /min was recorded under grassland compared to that of crop land which averaged 1.28 mg/m^2/min. emission from grazing land did not differ from cropland.

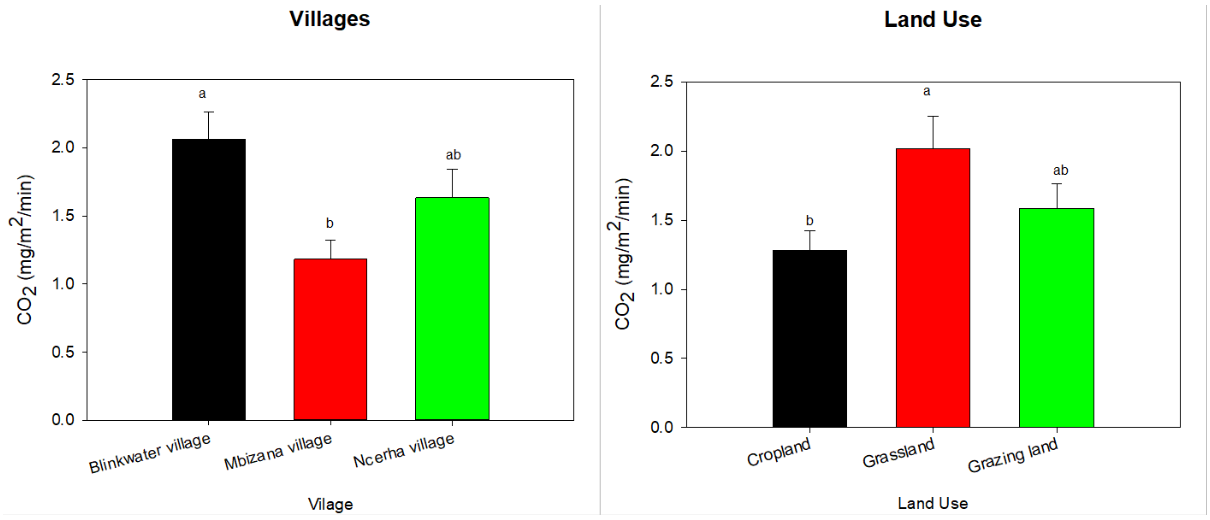


Figure 4.12: Effect of Land Use and Village on CO_2 emission rates in the Eastern Cape.

When data were analysed per village. The results showed that in Blinkwater village, grasslands had higher soil emission rates compared to the other two land uses (Figure 4.12). Grasslands had more than double the rate observed in grazing lands. At Mbizana, grasslands also had higher soil CO_2 emission rates compared to croplands but did not differ from grazing lands. At Ncerha village, soil CO_2 emission did not vary among all land use systems but grazing lands showed a tendency of higher values. When data were separated according to land use, significant differences between villages were observed (Figure 4.13). For crop lands alone Blinkwater village released CO_2 at a higher rate compared to the Mbizana village but did not vary with Ncerha village. For grasslands, Blinkwater village also had higher CO_2 emission rates compared to Mbizana and Ncerha which did not differ. Soil CO_2 emission rate in grazing lands did not differ among the villages.

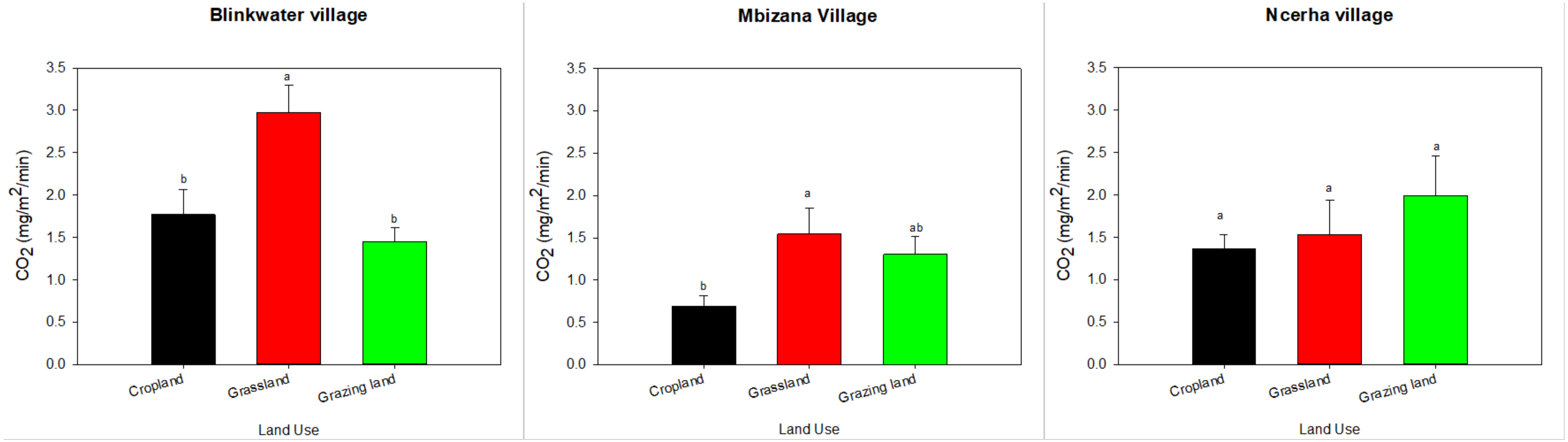


Figure 4.13: CO_2 emission rates between different land use systems in the three villages in the Eastern Cape Province.

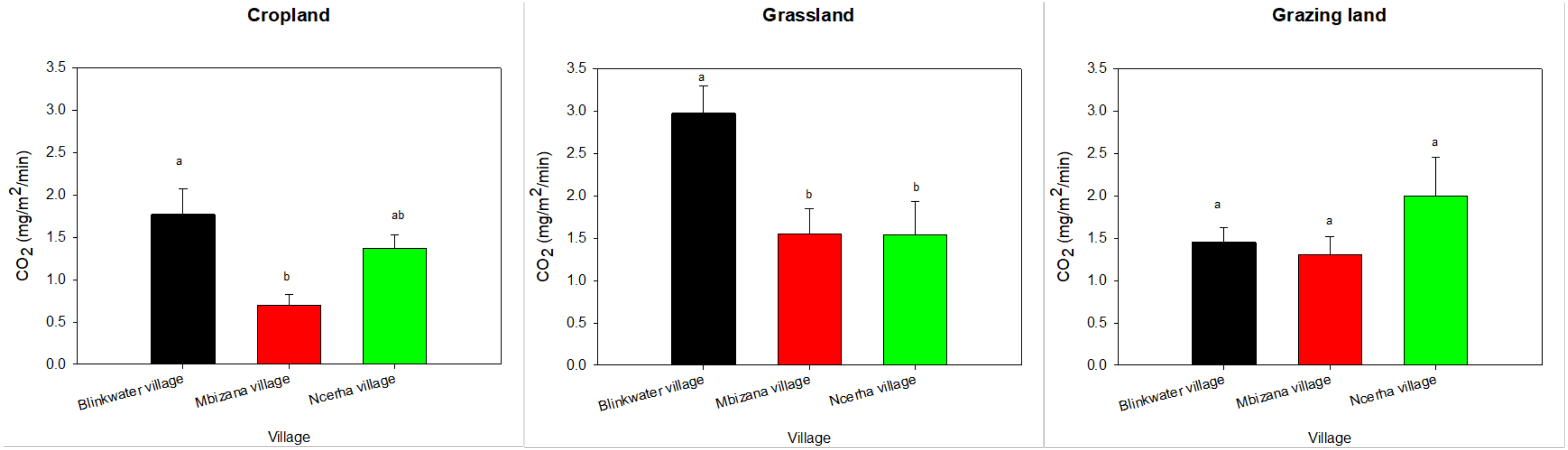


Figure 4.14: CO_2 emission rates between different villages with similar land use in the Eastern Cape Province.

4.7 Discussion

The findings of our study so far have shown that land use systems have a significant influence on soil CO_2 emission rates. These differences were observed in both the Letaba catchment in Limpopo and the Keiskamma catchment in the Eastern cape.

In the Letaba catchment where nine land uses were studied over a period that covered almost three distinct seasons, it was observed that some land uses release more CO_2 in the autumn season while others picked up in winter going into the spring season. In the natural systems, the forest thicket released more CO_2 in autumn compared to the bushlands and this can be attributed to a combination of higher residual soil moisture levels (See Figure 4.6) and organic carbon in the thicket. The open bushlands allow more evapotranspiration from the soil compared to the thicket. The thicket provides some shading and reduces heat from the sun and thus lowering surface temperatures and water loss (Anokye et al., 2021). Our surface temperature results (Figure 4.9) showed a significantly lower temperature in the forest thicket compared to the bushlands in the autumn. Reports have also shown that there is generally higher organic carbon in forest thickets compared to open bushlands (Shi et al., 2014; Kempen et al., 2019) due to more litter fall, reduced soil temperatures ((Zhang et al., 2021; Markham and Anderson, 2021) and decrease decomposition rates and thus may result in higher CO_2 emission rates. The results of this study indeed found that there was a higher amount of OC in the forest thicket compared to several other land use systems.

Our findings in the Letaba catchment also show that land use systems that are irrigated (banana, avocado and citrus) tend to maintain relatively higher soil CO_2 emission levels in winter and into the spring (Figure 4.6). This is mainly because the soil moisture conditions are more favourable for microbial activities compared to drier conditions experienced in other land uses. Soil moisture and temperature are the most important factors influencing CO_2 emission from soil (Rastogi et al., 2002; Qu et al., 2020; Li et al., 2021; Wu, 2020). Thus, in an area like the Limpopo which receives unimodal rainfall in summer, soil moisture levels in the non-irrigated system are low in the dry seasons and hence the low soil CO_2 emission rates. The results of this study also revealed a strong influence of environmental temperatures on soil CO_2 emission rates. Though the impact of season was not statistically analysed, the results in Letaba show a tendency of higher CO_2 emissions in the autumn compared to winter and spring (Figure 4.6). Similar results were also reported by (Munjonji et al., 2021) in irrigated citrus in the same catchment. However, current results are revealing that the trend is different for irrigated and non-irrigated land use. Irrigated land use systems revealed a trend of higher emission rates in autumn, decreasing in winter and rising in spring while on the other hand, the non-irrigated remained low in winter and the spring months. The differences are brought about by the differences in soil moisture as alluded to earlier.

In the Keiskamma catchment in the Eastern Cape where only three land use systems were studied and only measured in the spring season, it was observed that grasslands released more soil CO_2 compared to croplands but did not differ with grazing lands. The differences could be attributed to the differences in organic matter that normally exist between cultivated and non-cultivated areas. Grasslands, particularly the one studied in the Keiskamma, which is enclosed and has not been grazed for several years tend to have higher organic matter accumulation compared to cultivated lands which lose a lot of carbon due to enhanced oxidation brought about by tillage (Yu et al., 2020; Lai et al., 2016). The lack of differences in CO_2 emission observed between grazing lands and grasslands could have resulted from the addition of organic matter in the form of dung from the grazing livestock. Differences were also observed in the average amounts of CO_2 emitted between the villages (Figure 4.11). The differences may be due to differences in the soils, micro climates, vegetation and even the management practices. This information would be gathered and reported in the next report.

The results from Keiskamma showed a significant interaction between the village and land use thus land use systems performed differently in CO_2 emission depending on which village they come from. For example, In the Blinkwater village, grasslands showed higher soil CO_2 emission rates compared to grazing and crop lands while in the Ncerha village, no significant differences were observed between the land use systems (Figure 4.12). The reason for such differences is not clear yet but would be revealed as more readings are taken and more explanatory values are explored. The same challenges were also observed in the Letaba catchment where a lot of explanatory variables have not been analysed to have a complete picture of the sources of soil CO_2 variation in the catchment.

Due to the limitation of data in the Keiskamma catchment, cumulative CO_2 emitted could only be calculated and reported for the Letaba catchment. So, from March to September 2021, the cumulative amount of the emitted soil CO_2 differed between the land use systems. Higher amounts of CO_2 have been emitted from banana plantations and citrus orchards. In the six (6) months, more than 14 tons have been emitted in each of these two systems compared to about 6 tons and 9 tons in the bushlands and maize fields respectively. This shows that perennial irrigated crops contributed more CO_2 to the atmosphere compared to annual rain fed crops. In the same catchment citrus was reported to release about 35 tons of CO_2 into the atmosphere in a year (Munjonji et al., 2021).

4.8 Conclusions

The findings of our study so far show that soil CO_2 emission rates vary with land use systems as revealed by the results from the two catchments. The results also suggest that the impact of soil moisture depends on whether the land use system is irrigated or not. Thus, soil moisture was found to be the main factor influencing soil CO_2 emissions in non-irrigated land use systems while temperature was the most important factor. In the Eastern Cape, it was observed that while land use influenced soil CO_2 emission, microclimates also have an impact as differences were observed between different villages. However, more soil and climate data still need to be collected to have a better understanding of the drivers of CO_2 emission in the catchments.

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Chapter 5: Socio-Economic Drivers of LULC Changes Along with The Mitigation and Adaptation Strategies

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5.1 Abstract

Land use and land cover changes are seemingly inevitable. It has been happening worldwide causing mixed ecosystem impacts and notable disruptions to both livelihoods and natural ecosystems. Understanding land use and land cover changes is critical for environmental management and climate change policy. Changes are attributed to various socio-economic, geographic, and biological factors. However, most studies continue to neglect the important linkages and information generated from the combined analyses of these changes and information on the drivers of land cover change. This study undertook a triangulation analysis integrating satellite observations and perception surveys to establish convergence, complementarity, and dissonance of results on LULC and perceived changes in three different catchments, Letaba catchment, Keiskamma catchment and Mthatha catchment. While acknowledging that LULC has occurred in the three catchments, an attempt is made using multiple methodologies to understand the underlying processes and key socioeconomic factors deriving these processes.

The status quo of the economic and social drivers of land use and land use cover (LULC) changes in the Letaba River Catchment (Limpopo province), Keiskamma catchment (Eastern Cape), and Mthatha catchment was determined through a comprehensive and systematic review of land use change drivers. In addition to the literature review, three cross sectional surveys were undertaken in all three catchments. House-to-house survey questionnaire across communities located in three catchments gathering similar information to allow comparative analyses across the catchments. The questionnaire had both open-ended and closed-ended questions to gather household socio-economic variables, data about drivers of LULC and perceived change and their drivers as understood by the communities, and the mitigation and adaptation strategies that can be used to address the LULC problems. Focus group discussions were also employed with elderly and community representatives. Descriptive statistics were used to analyse quantitative data, while narration was used to analyse qualitative data.

In terms of socioeconomic characteristics, female-headed households were prominent in the Mthatha catchment and Letaba catchments accounting for close to 60% of the sampled households. Approximately 100% of the sampled households in the Letaba catchment indicated that land use was changing, with 94% and 63% in Mthatha, and Keiskamma catchments respectively. However, there were mixed perceptions about when the most change happened in all three catchments. More than 50% have indicated that this has been happening for more than 10 years. An increase in built-up area was reported from the sampled households across the three catchments concurring with the satellite images. There was an observed incidence of convergence of perceptions and actual LULC as observed from satellite images and some incidence of disagreement. Population growth and urbanisation featured as prominently in literature as drivers of LULC in the three catchments. There was significant convergence of respondents' perceptions about the most important drivers of LULC across the three catchments. Demand for new residential areas, farm abandonment, population growth, poverty, lack of financial resources, and climate change emerged as the most important drivers of land use change while land use policies, law enforcement, and lack of awareness were ranked as least important. Respondents across the three catchments concur that education and awareness on land use and enforcement of rules against the harvesting of resources and improper land allocation are key to ameliorating the land use change problem.

5.2 Introduction

Understanding land use and land cover changes are critical for environmental management and climate change policy (Searchinger, Witsenius and Dumas, 2018). Land use/cover changes have been happening worldwide causing mixed ecosystem impacts and notable disruptions to the natural ecosystem (Tahiru et al., 2020). The ecological changes impact the environment and the distribution of ecosystem services through multiple, dynamic, complex, direct, and indirect, making it difficult to document the pathways (Campbell et al., 2005). Land use and land cover changes are seemingly inevitable, and rapid changes are expected soon. The rapid changes can be attributed to various socio economic, geographic, and biological factors. These changes have led to an increase in literature describing changing patterns of land cover and land uses globally (Campbell et al., 2005; Caspell and Vasseur, 2021). The last decades have seen a proliferation of studies assessing the nature, magnitude, and drivers of land use and land cover changes and their relationship with GHG emissions. However, most studies continue to neglect the important linkages and information generated from the combined analyses of these changes and information on the drivers of land cover change.

There are numerous factors causing changes in land use and land cover (Arowolo et al., 2018). These factors can be categorised into human and natural factors. Human factors are mostly associated with the size, and growth of the human population and economic activities, whilst natural factors are mostly associated with climate (Liping et al., 2018). Increasing population growth contributes to LULC changes, particularly from the perspective of demand for the built-up area, agricultural activities, and water resources. Land use and land cover changes can subsequently lead to a decreased availability of different products and services for humans, livestock, agricultural production, and damage to the environment (Tahiru et al., 2020). Understanding the drivers of land use/land cover changes is still a confounding question in global science, and more research is still needed because these drivers are still argumentative and differ across contexts (Geist and Lambin, 2001). The globally identified drivers of land use land cover (LULC) changes are location-specific, varying from region to region depending on the socioeconomic and biophysical factors prevailing at that location (Li et al., 2016; Caspell and Vasseur, 2021). In some regions, population growth, high poverty levels, settlements, fuelwood, charcoal production, and agricultural expansion are reported as the main drivers of LULC changes (Kamwi et al., 2015).

Structured information on both land use/land cover changes and socio-economic variables responsible for these changes could facilitate the identification of area-specific drivers of these changes and the associated exogenous national and international forces (Lo and Yang, 2002). After the identification of land use and land cover patterns in the three catchments (Chapter 1), which is the focus of this report is to employ multiple methodologies to understand the underlying processes that transform land use practices and continuously promote new trajectories of land uses and land cover changes in the three catchments.

5.2.1 Socioeconomic drivers of land use change in the Letaba, Keiskamma and Mthatha River Catchments

A consensus is emerging in the literature that studying land use and land cover changes patterns, causes, consequences, mitigation, and adaptation strategies require the integration of human, social, geographical information, and natural sciences (Mirmoghtadaee, 2012 and Hettig, Lay and Sigangule, 2015). Many are of the opinion that land use/land cover process are fundamentally driven by humans, and are a function of human social processes, and could best be understood through models that include human behavioural components. Unlike previous studies that fail to acknowledge this sentiment, studies on land use/land cover change with a socioeconomic dimension are becoming popular (Mirmoghtadaee, 2012). Land use and land cover changes are largely derived from changes in population, food systems, technological innovation, globalization, rural transformation and urbanization, community power relations, environmental and political fragility, and governance among others. Figure 1 below presents the key elements of the framework used in this study following the estimate of land use change per category in the three catchments, namely, Mthatha River Catchment, Letaba catchment and Keiskamma catchment. In addition to the established land use and land cover patterns, this deliverable seeks to synthesise from both physical and socioeconomic information the socio-economic drivers of the observed LULCC guided by the framework presented in Figure 1 below.

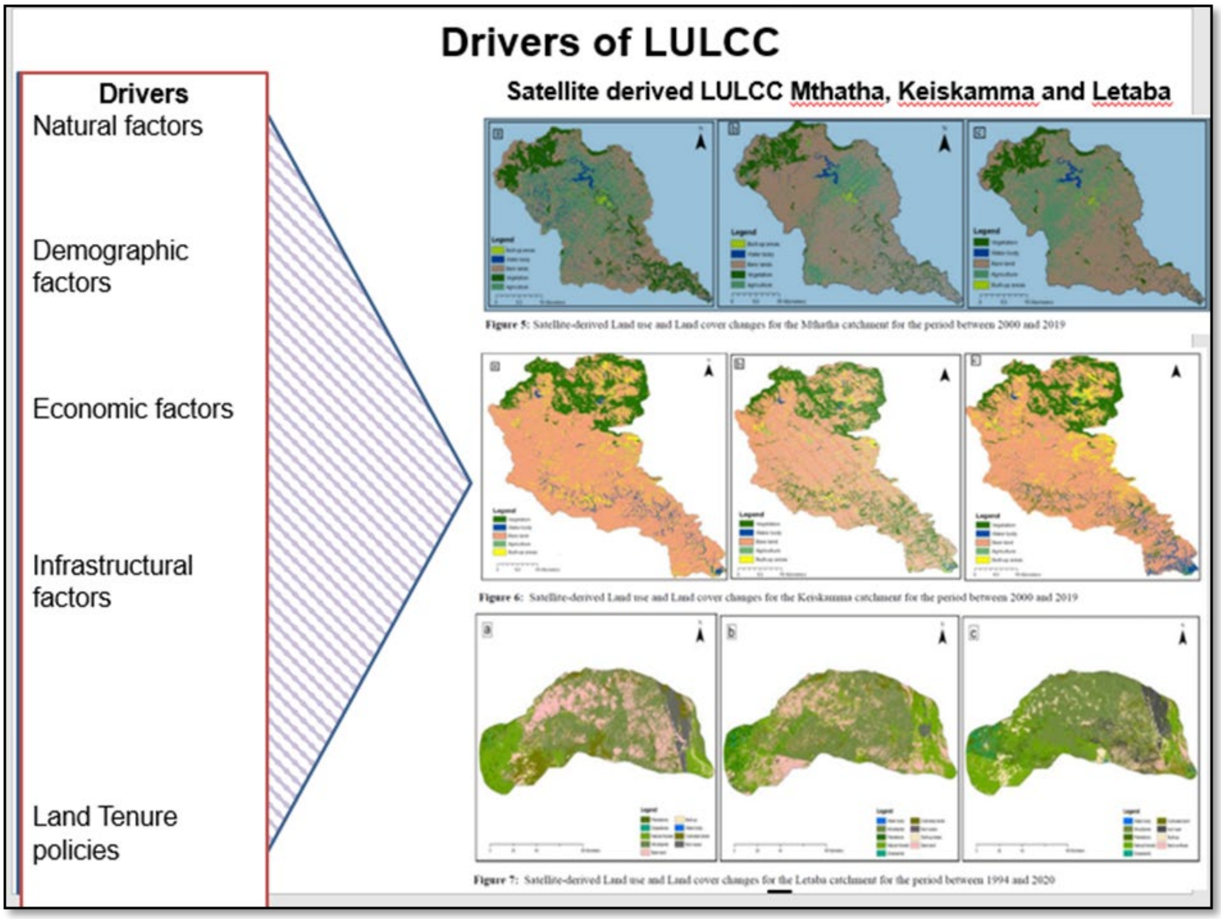


Figure 5.1: Drivers of land use and land cover change

While guided by the above framework and focusing specifically on the three catchments, the following review attempts to put into perspective the general trend in literature as well as catchment-specific literature on socioeconomic drivers of land use and land cover changes. The systematic review of drivers of land use changes in the three-catchment focuses on case studies reported in peer-reviewed publications independently done in the three catchments. A systematic search in Web of Science using the socioeconomic drivers and land use type and the name of the catchment as the keywords yielded a set of potentially relevant papers that were selected for analysed and eventual inclusion in this study. It is important to note that there were different studies carried out in the three catchments and in addition the subject matter, land use change is not well researched. In Mthatha River Catchment; most of the focus is on water quality research.

5.2.2 Drivers of land use change in Mthatha River Catchment

This section summarises information gathered from literature documenting land use change in the Mthatha river catchment and the associated drivers. Despite the relevance of the catchment to the region in general, it is important to point out that few studies were undertaken in the Mthatha Catchment (6 studies) and all six studies were used for the current and systematic analyses. These studies span 21 years, from 1996 to 2017. Of the 6 cases included, 12 arguments were mentioning the drivers of change in agricultural land, 8 on built up areas, 7 changes in water bodies, 2 on vegetation land and none on bare land. Table 5.1 below shows the summarised results of the review and analyses.

Results from the reviewed documents show that the most underlying drivers in order of frequency are as follows: Land tenure and human settlement policies, migration, urbanisation and population growth. These factors are associated with either increase in specific land use or a decrease in specific land use depending on both the land use type and its geographical location. The relative importance of each of the identified drivers for all the types of land uses is presented below in Table 5.1.

Table 5.1: Socioeconomic drivers of land use changes in the Mthatha Catchment

Drivers of land use and land cover change	**Source**	**Number of papers which identified the driver**	**Arguments**
Population	Mabandla (2015) Philips and Porter(1996); Mangwale et al. (2017)	3	Rapid population increase puts pressure on the need for settlement land, resulting in the conversion of agricultural, water bodies and grazing lands to settlement
Population density	Philips and Porter(1996); Mangwale et al. (2017)	2	Land use intensification results in reduced vegetative cover
Number of households	Nhlapo et al., 2011 Siyongwana (2005)	2	The number of households has been on the increase within the urban part of the catchment, in the process exerting pressure on the need for residential settlements
Economically active population	Mabandla (2015)	0	

	Siyongwana (2005)		
Urbanisation rate	Mabandla (2015) Philips and Porter (1996); Mangwale et al. (2017)	3	The problem of urban land access results in the change of agricultural/bare land into settlement and business area
Migration	Philips and Porter (1996) Nhlapo et al., 2011; Siyongwana (2005)	3	Large scale net migration to bigger cities. The concentration of people in urban spaces of the catchment Post-Apartheid era
Regional gross domestic product		0	Collapse of manufacturing industry contributing to out-migration
Precipitation	Mangwale et al. (2017)	1	Reduced precipitation discouraged rainfed agricultural activities and is likely to result in a change in LULC with respect to water bodies
Access to piped water	Mangwale et al. (2017)	1	Has an impact on the livelihood option used by households which can put pressure on water bodies
No Access to electricity	Mangwale et al. (2017)	1	Results in the clearing of forests in pursuit of wood fuel for food preparation. The use of fire as fuel increases the risk of uncontrolled fires which affect land cover

Droughts index	Mangwale et al. (2017)	1	Recurrent drought can result in the shrinkage of water bodies and well as a shift in agricultural land
Dependency on natural resources	Mabandla (2015) Siyongwana (2005)	2	Expansion of agricultural lands as a result of accumulation which affects agricultural land and water bodies
Land tenure policies and Human settlement policies	Philips and Porter (1996), Tropp (2003) Nhlapo et al., 2011 Mabandla (2015) Siyongwana (2005) Mangwale et al. (2017)	6	Betterment (1940s) schemes led to further ecological deterioration. The need for better housing facilities for the population of the catchment leads to changes in land use and land cover Destruction of traditional land holding powers Reconstruction and Development program led to the establishment of settlements within the Mthatha. Traditional council ownership of land
Literacy level	Mabandla (2015)	1	With increasing literacy level and education, children of subsistent

			farmers are more interested in intensive agricultural production, thus increasing area under agricultural production by black farmers
Changes in technology	Mabandla (2015)	1	Improved literacy levels facilitates use of technological equipment that support agricultural activities
Wealth index/Poverty levels	Nhlapo et al., 2011; Mangwale et al. (2017)	2	Small proportion of middle working class. High poverty levels in the catchment which compel people to put pressure on the natural resources to derive livelihoods

Demographic factors, climatic factors and technological drivers were mainly mentioned in the context of agricultural and settlement land use change. Institutional drivers, mainly related to policy changes and location factors were identified mainly in relation to agricultural land and built-up areas. It is important to note that agricultural and built-up areas emerged as the most affected land use activities. Although important and frequently mentioned in literature on drivers of land use and land cover change, economically active population and the regional gross domestic product did not appear as a factor in any of the studied documents for the Mthatha catchment. The advent and impact of policy-driven changes across the catchment were well documented.

5.2.3 Socio-Economics drivers of land use change in the Keiskamma Catchment

The Keiskamma catchment is relatively undeveloped with most land being communal and used predominantly for stock grazing or dry land cultivation (DWAF, 2008, 2010). Less than 1 500 ha is cultivated under irrigation. The largest scheduled irrigation areas include the Keiskammahoek (854 ha), Zanyokwe (471 ha) and Tyume (231 ha) irrigation schemes in the upper catchment. Commercial forestry (less than 1000 ha) is located in the Hogsback and Upper Keiskamma catchment in the higher rainfall areas in the Amatola mountain range. The majority of the area once fell within the borders of the former Ciskei and the residential settlement pattern is mainly scattered rural type villages located throughout the catchment. The main formal towns in the area are Hamburg at the mouth of the Keiskamma River and Alice, Middledrift and Keiskammahoek in the upper catchment (DWAF, 2008, 2010).

A study by Ndou (2013) showed that between 1984 and 1999, there was a decline in pristine vegetation and an increase in degraded vegetation and exposed soil in the Keiskamma catchment. According to Mhangara & Kakembo (2012), between 1972 and 2006, Keiskamma catchment land changes show increases in degradation, with periods of decline and recovery. There has also been a decrease in vegetated areas. The riparian and hillslope proximal zones also show some evidence of fragmentation. This could be attributed to anthropogenic impacts, such as overgrazing, cultivation and the permanent loss of saturation induced by river impoundments. The semi-arid communal areas in the central Keiskamma catchment showcase increasing degradation trends, particularly vegetation fragmentation.

Vegetation condition is influenced by the strength or weakness of local institutions responsible for coordinating grazing and land management in communal areas. Degraded vegetation is more prevalent in villages with weak governing institutions, while strong traditional institutional practices, which regulate grazing activities and enforce community rules still maintain reasonably healthy vegetation conditions.

Dyosi, Tesfamichael, Pillay, & Zhou (2018) found that in the Keiskamma catchment, between 2000 and 2016, bushes increased by 5%, dense forests decreased by 16%, grass areas increased by 9% and cultivated land decreased by 1%. Deforestation, increase in human settlements and drought conditions were the main drivers of the decrease in dense forest and cultivated land, especially between 2014 and 2016 (Dyosi et al., 2018). The bush increased due to the suppression of fire and rainfall variability. Bare soils/built-up areas increased by 2% (Dyosi et al., 2018). The land use and cover changes as alluded to by Mhangara & Kakembo (2012) are a result of the socio-economic status of the Keiskamma catchment. The catchment covers part of Buffalo City Metropolitan as well as Amathlati, Ngqushwe and Raymond Mhlaba Local Municipalities. The next sections will discuss the socio-economic characteristics of these municipalities and their linkages with changes in land use types while paying special reference to areas that fall within the Keiskamma catchment.

5.2.4 Buffalo City Metropolitan

Buffalo City Metropolitan measures 2 750 km^2 (Figure 3) (IDP, 2017; Municipalities of South Africa, 2021). It has a population of 884 000, with 52% females versus 48% males in 264 000 households. Over 40% of the people in Buffalo City Metropolitan are in poverty (IDP, 2020). The area has a well-developed manufacturing base, with the auto industry playing a major role. The climate is mild, with year-round sunshine. The average rainfall is 850 mm. Economic activities include community services (25%), finance (24%), manufacturing (24%), trade (12%) and transport (12%). There is spatial fragmentation in Buffalo City, a feature of the entire municipality (IDP, 2017). Main use shows urban settlement dominating East London, Mdantsane, King William’s Town and Dimbaza It dominates the industrial and services sector. Rural and peri-urban settlements characterise the non-urban land within Buffalo City and accommodate 20% of the population or land used for intensive and extensive agricultural purposes (IDP, 2017). According to IDP (2020) 41.2% of the municipal land cover is Thicket and bushland, 9% is cultivated on semi-commercial/subsistence basis, 10% of the land is degraded and 7.8% is urban or built up residential. Wards 34, 36 (Dimbaza) and 40 (Twecwana) in Buffalo City Metropolitan are part of the Keiskamma catchment. They have the following characteristics (Table 5.2).

Table 5.2: Characteristics of wards in Buffalo City Metropolitan which fall under the Keiskamma catchment

Ward	Name	Size (km^2)	Population	Households	Males (%)	Females (%)	Major socio-economic issues affecting land use
34	Dimbaza	9.66	20 400	6 031	46	54	Construction of multi-purpose centres, school closures and rural electrification (IDP, 2020)
36	Dimbaza	2.60	68	18	51	49	
40	Twecwana	1.03	571	153	51	49	

Amathlati Local Municipality

Amahlati is an isiXhosa name that means ‘a place where many trees are grouped together, a forest'. Forests are a key feature of the area. It has an area of 4 505 km^2 and the main economic activities include community services (37%), finance (27%), manufacturing (18%), trade (10%), agriculture (4%), construction (2%), transport (2%) (Municipalities of South Africa, 2021). The following wards in Amahlathi Local Municipality are part of the Keiskamma catchment.

Table 5.3: Characteristics of wards in Buffalo City Metropolitan which fall under the Keiskamma catchment

Ward	Name	Size (km^2)	Population	Households	Males (%)	Females (%)	Major socio-economic issues affecting the area
1	Gxulu Boma Pass Keiskammahoek	19.01	7 046	1 738	47	53	Establishment, maintenance and extension of water taps (IDP, 2021a)
2	KwaMxhalanga	2.37	1 330	384	46	54	
3	Gwiligwili	3.01	1 686	549	49	51	

10	Rabe Madubela	6.43	1 587	479	45	51	
11	Upper Ngqumeya	1.06	1 218	320	47	53	

Ngqushwa Local Municipality

Ngqushwa Local Municipality is bordered by the Keiskamma River to the east and the Great Fish River to the west. The southern boundary comprises part of the coastline of the Indian Ocean. Ngqushwa is one of the smaller municipalities in the district, accounting for 10% of its geographical area at 2 115 km^2 (Municipalities of South Africa, 2021). It is predominantly rural in nature. The main activities are agriculture and tourism. There is widespread land abandonment in Ngqushwa. There has been widespread overgrazing (Kakembo, Xanga, & Rowntree, 2009) Some of the characteristics of wards in Ngqushwa that fall under the Keiskamma catchment is shown in Table 5.4.

Table 5.4: Characteristics of wards in Buffalo City Metropolitan which fall under the Keiskamma catchment

Ward	Name	Size (km^2)	Population	Households	Males (%)	Females (%)	Major socio-economic issues affecting the area
1	Zalara Gobozana Tamara Ngele Nonibe	9.63	4 661	1 184	47	53	Construction, maintenance and renovations of community halls, street light installations, road construction, construction of RDP houses (IDP, 2021b). According to (Palmer, McGregor, Hill, & Paterson, 2010) coastal towns in Ngqushwa such as Hamburg have experienced low density informal development with a very low increase in formal development. This has been exacerbated by worker
12	Hamburg	10.85	1 348	454	51	49	

	migrations into towns such as Buffalo City. Some of the drivers to land use changes especially for coastal areas were economic (employment opportunities, global trade developing ports, tourism), social (livelihood needs, aesthetics, provision of amenities) (Palmer, Hill, McGregor, & Paterson, 2011)

Raymond Mhlaba Local Municipality

Raymond Mhlaba Local Municipality is the largest municipality of the six in the district, covering 6 357 km^2 and making up a third of its geographical area (Municipalities of South Africa, 2021). Tourism is a key sector having a rich heritage and history. In the area, 10% of the surrounding landscape has natural vegetation, watercourses and natural wetlands; 90% of the majority of areas surrounding the roads are transformed by human activities, with farm dams being constructed (Municipalities of South Africa, 2021). Wards that dually fall within Raymond Mhlaba and the Keiskamma catchment area are shown in Table 5.5.

Table 5.5: Characteristics of wards in Buffalo City Metropolitan which fall under the Keiskamma catchment

Ward	Name	Size (km^2)	Population	Households	Males (%)	Females (%)	Major socio-economic issues affecting the area
1	Mnqaba Kulile	2.09	1 252	364	45	55	Issues include electrification of new extensions, provision of free basic electricity, regravelling and upgrading roads in villages, sports field, community hall construction, RDP housing, house construction in Hertzhog, rehabilitation of tourist sites in villages, reviving irrigation in
5	Mgquba	2.04	1 014	303	48	52	
6	Alice	1.97	1 300	408	54	46	
10	Jomlo Kwanomadolo	4.6	703	207	50	50	
11	Alice	2.17	4 696	150	46	54	
12	Evergreen Melani Majwareni Rwarwa	4.43	1 903	702	48	52	

13	Fort Willshire Dlawu Kudikidkana	3.31	1 859	518	48	52	Qamdobowa, Zalaze, Gqadushe, Sityi, grazing land fencing, dam scooping, school renovation, clinic construction in Mgxotyeni, toilet installations, revitalising and establishing diptanks, repairing windmills, provision of bus service to Msomuvubu, fishing projects at Magaleni, Guqawe, Lower Gqumashe, Skhutshwana, resuscitation of citrus farms in Woburn, Taylor, alien species removal, processing of African potatoes, appointing camp rangers, I improving food nutrition (IDP, 2016). Alice town is a natural area, low density residential, medium density residential, dam or reservoir, retail commercial and warehousing, filling station, agriculture, river, stream or wetland, railway line, police station, quarry, sand, historical building, archaeological site (EOH Coastal and Environmental Services, 2017). Issues include upgrading electrification, regravelling and upgrading roads, community house construction, training on agricultural skills
14	Manqulweni Exesi Kwacapo Kwasityi Ngwenya	1.82	1 422	432	48	52	
15	Mtombo Edrayini Tyutyuza Ncera Dyamala	2.04	1 987	559	50	50	
16	Gudwini Kwamfiki	0.31	267	67	54	46	
17	Maipase Lolni Zihlahlena	3.61	2 576	665	48	52	

	development, sanitation in Alice town (IDP, 2016). Fort Hare is predominately human settlement; Some of the issues include electricity supply for houses, establishment of irrigation schemes and dam scooping, sanitation, regravelling and upgrading roads (IDP, 2016).

5.2.5 Socio-Economic Drivers of LULC Changes in the Letaba river catchment

A desktop analysis was undertaken to determine the status quo of the economic and social drivers of LULC changes in the Letaba river catchment (LRC). The Letaba Catchment is characterised by large dams, of which the majority are concentrated in the upper reaches of the Letaba, irrigated orchards, rural settlements, and subsistence agriculture (with the often associated overgrazing, trampling and erosion) and the conservation areas at the lower end (Kruger National Parks and Letaba Ranch). The study area is located in a region that is largely rural with several regionally important urban nodes and smaller satellite towns, as well as rural settlements. The land uses in the area are Commercial Agriculture and Plantation, Subsistence agriculture, Rural Closer Settlement-Subsistence, High Density Formal Urban, and Recreational/Dams/Game Farms. Land use in the Letaba Catchment consists largely of nature conservation in the form of national, provincial and private nature reserves and forest reserves. The primary land use along the rivers is citrus and sub-tropical fruit production, with grazing in the less fertile sandy loam soils. Removal of the vegetative cover by overgrazing has led to erosion in some places, resulting in an increased sediment load in the rivers (Department of Water Affairs, 2013). There was a significant land cover change from forest land, woodland and open grassland to medium-size farms, subsistence agriculture and built-up land from a classified image showing the land cover change for the catchment between the 1980s and 2000. There are a number of factors that contribute to land use changes including population increase, poverty, and the use of land for agriculture and grazing (Phethi & Gumbo, 2019).

Phethi and Gumbo (2019) found that Population increase was one of the factors that were influencing land use change in the study area. According to the authors, population growth increases the demand of land for food and settlement, thus leading to the intensification of agriculture and expansion of cultivated land. According to Makhado Municipality (2009), in 2000 the total population was 2540 and this rose to 4134 in 2006. This high rate of population growth causes a change in land use as more households seek new land to construct houses and for agricultural purposes. This is further attested by Naibbi et al. (2014) who found that the population increase added pressure on human settlement expansion on new virgin lands, leading to land use change favouring human settlements. The expansion of human settlements in wetlands is one way of relieving pressure on existing land use change (Tian et al*.,* 2015).

Phethi and Gumbo (2019) further found that the households in the area have larger family sizes of a maximum of 5-8 members in a family. This is similar to the study of Rananga and Gumbo (2015) who showed that larger family size was the norm in the rural communities of South Africa. As these family members become older, they would seek new virgin land for their own settlement and to practise subsistence agriculture, thus exerting pressure on the available land.

Poverty is another factor that contributes to land use change. Poverty has forced people to practise subsistence agriculture (Nguyen et al*.,* 2017). As a result of low or non-existence earnings, the respondents resort to subsistence agriculture. This implies that the land that is available is near or in the wetland, and the availability of water for irrigation leads to wetland degradation (Nguyen et al*.,* 2017). The other option is to overexploit the natural resources, found in wetlands, such as fish, thatching grass and sedge to make handbags, mats, hats and baskets to sell as their source of income to support their families.

5.2.6 Agricultural land use

A large proportion of the population relies on subsistence farming. Intensive irrigation farming is practised in the upper parts of the Klein Letaba River catchment, upstream and downstream of the Middle Letaba Dam, and particularly along the Groot Letaba and Letsitele rivers. Land use in the catchment upstream of the Middle Letaba Dam is characterised by irrigated crop farming where tomato is the major crop (DWA, 2013). Subsistence agriculture in deforested areas was dominant on higher grounds while remnants of wooded grassland occupied the depressions and lowlands. Land cover classification according to Anderson (1977) and Calder (2003) in the LRC was comparable. Both classifications showed agriculture was the dominant land cover followed by build-up areas. However, recent remote sensed classification of LULC showed that of recent the land cover/use type that gained dominance, while bare surfaces were losing dominance was observed to be built-up areas, which increased from 5481 ha in 1994 to 118476 ha in 2020, and plantations have faced an increment in the total area from 1994 to 2020 (see Chapter 1).

Agroforestry was prominent in the Tsianda area where the main tree crops include mangoes, guavas and litchis. This is a land management approach that deliberately combines the production of trees with other crops and/or livestock. The system is designed to yield a variety of marketable crops and environmental benefits and blends agriculture and forestry with conservation practices and strives to optimise economic, environmental, and social benefits. It involves intensive management of trees, non-timber forest crops, agricultural crops, and animals on traditional agricultural and forest lands. Agroforestry systems vary depending on the available resources and the outcomes desired. Different management practices will yield different products or functions such as wind protection or soil conservation.

5.2.7 Urbanisation

Urbanization often has more severe hydrologic effects than other forms of land use. When vegetation is replaced with impervious surfaces in the form of paved roads and parking lots, more surface runoff occurs, groundwater levels drop and baseflow decreases accordingly. Accordingly, urbanization results in increased surface runoff and correspondingly higher peak flow following storms. A report by WRC, 2015 indicated that there was an evident loss of forest cover in the reserves which was both clear cut and progressive thinning. Subsistence agriculture in deforested areas was dominant on higher grounds while remnants of wooded grassland occupied the depressions and lowlands. Land cover classification according to Anderson (1977) and Calder (2003) in the LRC was comparable. Both classifications showed agriculture was the dominant land cover followed by build-up areas. This trend is being replaced by a rapid increase in the built-up area, followed by agriculture.

5.2.8 Urban/Built-up Area

The Vhembe District Municipality is undergoing rapid urbanization, where rural land is being converted into urban land. This is evident in the catchment areas around Thohoyandou, Elim and Mhinga (DWA, 2013). The urban centres had expanded in size from what they were in 2003 and new ones were introduced. Furthermore, there was rapid urbanization which was converting rural land into urban land use, especially between Lwamondo and Thohoyandou.

Developments on hillsides, saddles and bottom lands were found in Tshakhuma, Lwamondo, Tsianda, Thohoyandou and Mhinga. The major land use in Tshakhuma and Tsianda was agroforestry and built-up land, whereas Thohoyandou and Mhinga were mainly built up which extended up to summit surfaces. This aligns with results from Chapter 1 which shows a major long term (1994-2020) decline in bare surfaces (-19.47%) and a major increase in built-up areas (12.18%).

5.2.9 Industrialization

With regards to industrial development, such industrial points are at Tzaneen (along the Groot Letaba River downstream of Tzaneen Dam), Nkowakowa and Giyani, with a number of sewage works spread throughout the catchment (DWA, 2013). There is little industrial or mining development in the catchment. Northern Canners at Politisi and the industrial complex at Nkowakowa near Tzaneen provide the major industries.

5.3 Materials and Methods

5.3.1 Primary data collection

A desktop analysis was undertaken to determine the status quo of the economic and social drivers of land use and land use cover (LULC) changes in the Letaba River Catchment (Limpopo province), Mthatha catchment, and Keiskamma catchment (Eastern Cape) through undertaking a systematic review of drivers for land use changes. In addition to the literature review, three cross sectional surveys were undertaken all the three catchments. House-to-house survey questionnaire across communities located in three catchments gathering similar information to allow comparative analyses across the catchments. The questionnaire had both open-ended and closed-ended questions gathering household socio-economic variables, data about drivers of LULC and perceived change and their drivers causes as understood by the communities, and the mitigation and adaptation strategies that can be used to address the LULC problems.

Participants were sampled to represent the various strata of the 3 catchments namely the lower, middle and upper catchment. From each stratum, participants were randomly selected to participate in the study. A total of 191 participated in Keiskamma, 183 in Mthatha and 186 in Letaba. Focus group discussions were also employed with elderly and community representatives. Qualitative notes were also captured to supplement the data that was captured through questionnaires. In addition, further in-depth interviews were carried out with identified knowledgeable community members.

5.3.2 Data presentation and analyses

Descriptive statistics were used to analyse quantitative data, while word cloud was used to analyse qualitative data gathered using questionnaires, key informants' interviews and focus group discussions. Before being coded, processed, and analysed using descriptive statistics like frequency and percentage in the Statistical Package for the Social Sciences (SPSS) version 26 software, data were manually checked for correctness. The data from across the three catchments was presented using tables which enabled comparing and contrasting of the findings.

5.4 Results and discussion

5.4.1 Household demographic characteristics

Socioeconomic and demographic characteristics of the sampled households in the Mthatha, Keiskammahoek and Letaba catchments are displayed in Table 5.6. Findings revealed that female (58%) headed households were prominent in the Mthatha catchment, with each household comprising a mean household size of 6. Almost all of the household heads in this catchment identified as black (99%) and were either married (48%) or single (31%). The mode age range was 51 to 60 (50%), whilst about 6% of the sampled households were child headed. Majority of the household head in the Mthatha river catchment attained either primary (32%) or secondary (47%) school as the highest education level, yet only 14% and 3% had attained tertiary education and no education respectively.

Fifty four percent of the household heads are reported to be unemployed under occupation, whilst 23% were employed. Consequently, the results revealed that crop government social grants (51%), farming (50%) and livestock production (43%) were the main sources of income identified by study participants. Employment ranked as the 4^{th} main source of income in the Mthatha catchment. Households hold own an average land size of 0.77 ha.

Comparing the socio-economic characteristics of the Mthatha catchment with those of Keiskamma, the results show a similar trend regarding gender distribution, race and level of education. Majority of the sampled household heads in Keiskamma were more than 60 years old (39%), followed by 51-60 years (27%) and 30-50 years (19%). Unlike in the Mthatha catchment, majority of the household heads in Keiskamma were single (45%) with 81% of the heads being unemployed.

Crop production, livestock production and government social grant ranked as the main sources of income with 62%, 55% and 27% respectively in the Keiskamma catchment. More households depended on social grants as their main sources of income in Mthatha (51%) compared to the Keiskamma catchment (27%).

In the Letaba catchment, majority (53.3%) of the households were male-headed with an age range of 30 to 50, unlike the other catchments which were predominantly female-headed. All respondents in Letaba had some form of education, whereby 42% had attained secondary education as the highest level.

Socio-economic and demographic characteristics are important in shaping community perceptions and behaviour towards land use and land cover change. Table 5.6 below demonstrates the socio-economic information of the sampled households in the three catchments.

Table 5.6: Socio-demographic characteristics of sampled households

	Keiskamma	Letaba Catchment	Mthatha Catchment
Gender of the head of household			
Male	40.8	53.3	42.1
Female	59.2	46.7	57.9
Household sizes			
Mean			6.29
SD			3.569
Household head age			
25 years	3.1	12.12	5.5
26-35 years	12	16.7	24
36-45 years	19.4	32.3	19.1
46-55 years	26.7	13.3	49.9
>55 years	38.7	25.6	1.6
Level of education of the head of household			
Not Educated	0.5	0	2.7
Informal Education	3.7	15.2	4.9
Primary Education	34	6.8	31.7

Secondary Education	52.4	41.4	47
Tertiary Education	9.4	9.9	13.7
Race			
Black	99.5		98.9
Coloured	00		1.1
White	0.5		
Asian			
Household head Marital status			
Married	41.4		48.6
Single	44.5		31.7
Separated	1.6		
Cohabitating	0		1,1
Divorced	4.2		1.1
Widowed	8.4		17.5
Household head occupation			
Employed	7.3	7.8	23.5
Unemployed	80.6	6.3	54.1
Pensioner	6.3	20	21.3
Self-employed	5.8	2.2	1.1
Household land size holding			
Mean			0.77
SD			0.313
Household main sources of income			
Crop farming	61.8		50.3
Livestock	55.5		43.2
Employed	11		24.6
Crafts/selling firewood	1		2.2
Own Businesses	14.1		12.6
Pension Fund	5.3		21.3
Grant	26.7		50.8

5.4.2 Community perception of land use change

Knowledge of perceptions on land use change is necessary for accurate decision-making in the move towards a more sustainable approach to land use change. The table below shows the perceptions of the sampled households regarding the land use change. All the respondents (100%) in Letaba catchment agreed that land use was changing, followed by those in Mthatha Catchment (94%) with Keiskamma Catchment having the least number (63%). In Keiskamma and Letaba catchments half of the respondents (50%) reported that land use has been changing for the past 10 years. It was in the Mthatha catchment where most respondents (61.7%) indicated that the change in land use change has been occurring for more than 20 years ago.

Table 5.7: Perceptions of land use change

Do you agree that the land use in your community is changing/has changed?			
Catchment		Yes	No
Keiskamma Catchment		63.4%	36.6%
Letaba Catchment		100%	-
Mthatha Catchment		94%	6%
Perceptions on when higher proportion of the land use change occurred			
	< 5 years	> 10 years ago	> 20 Years ago
Keiskamma Catchment	**38.2**	**50.3**	**11**
Letaba Catchment	**26.7**	**50.0**	**18.9**
Mthatha Catchment	**13.1%**	**25.1%**	**61.7%**

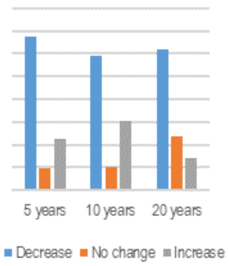
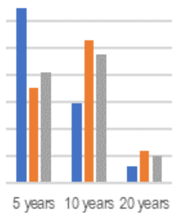
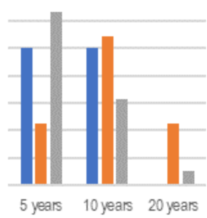
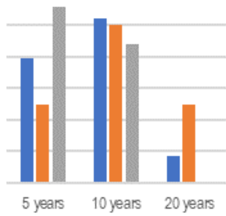
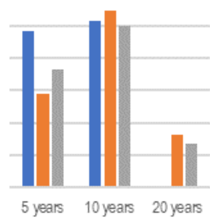
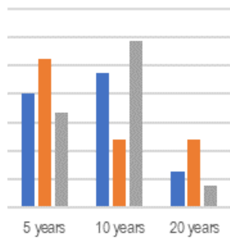
Results from the sampled households in Letaba and Mthatha catchment indicate that the majority, 100% and 94% of the participants respectively, perceived that land use was changing, as shown in Table 5.7. Even though participants in the Keiskamma catchment agreed with the view, fewer participants (63%) identified with this view as compared to Mthatha and Letaba catchment.

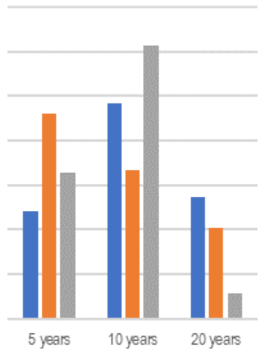
Tables 5.8 to 5.10 show the respondents' perception of LULC changes over different periods, ranging from 5 to 20 years. Table 5.8 shows that there was a significant association between changes in plantations, water bodies and grasslands in Keiskamma over a 20-year period. In the short term (i.e. 5 years), 63.2% of the respondents identified that plantations have increased while in the medium term (i.e. 10 years), 54.5% have identified that there has been no change. Only 22.7% of the respondents have indicated that there has still been no change in the long term (i.e. 20 years). In the short term, 56.0% of the respondents indicate that water bodies have increased, while in the medium term, 52.1% indicated that water bodies have decreased. Twenty five percent highlighted that there has been no changes in the water bodies in the long term. Around 52.4% of the respondents highlight that grasslands have not changed in the short term, 58.9% indicated that they have increased in the medium term and 23.8% assert that grasslands have not changed in the long term.

In Limpopo, there was a significant association between perceived changes in built up areas and water bodies over a 20-year period (Table 5.9). In the short, medium and long term, there were 91.3%, 84.4% and 57.1% of respondents who indicated an increase in built up areas, respectively. Close to 47.8% and 64.4% of the respondents highlighted that there has been no change in water bodies in the short and medium terms, but 47.6% highlighted that there was an increase in water bodies over the long term.

Table 5.10 shows that there is a significant association between perceived changes in built up areas and grasslands in Mthatha. In both instances, there has been an increase in built up areas and grasslands over the short, medium, and long term.

Table 5.8: Keiskamma land use changes vis-a-vis length in time

	Cultivated land	Built up areas	Plantations	Water bodies	Bare surface	Grasslands
Highest proportion of change						
Chi-square	5.53	4.11	20.32***	12.10**	5.89	9.91**
Cramers V	0.12	0.12	0.30***	0.24**	0.16	0.18**
	Natural forests					



Chi-square	14.78***
Cramers V	0,23***

Table 5.9: Limpopo land use changes vis-a-vis length in time

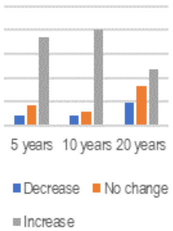
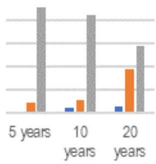
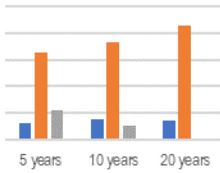
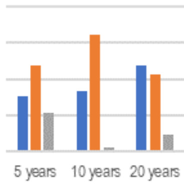
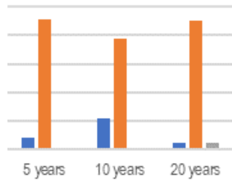
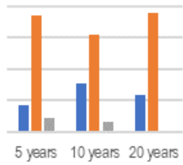
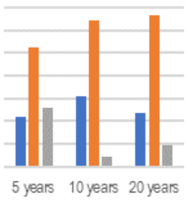
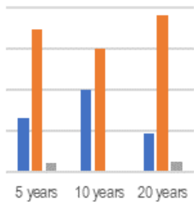
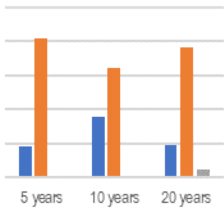
	Cultivated land	Built up areas	Plantations	Water bodies	Wetlands	Bare surface
Highest proportion of change						
Chi-square	7.60	10.32**	5.32	9.04*	7.43	3.35
Cramers V	0.21	0.24	0.24	0.23*	0.20	0.14
	Grasslands	Natural forest	Shrub land			
Highest proportion of change						
Chi-square	7.49	4.95	6.22			
Cramers V	0.21	0.17	0.19			

Table 5.10: Mthatha land use changes vis-a-vis length in time

<table>
<tr><th></th><th>Cultivated land</th><th>Built up areas</th><th>Plantations</th><th>Water bodies</th><th>Bare surface</th><th>Grasslands</th></tr>
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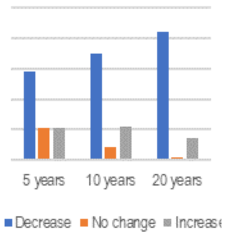
<td>
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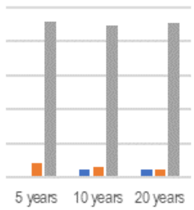
<td>
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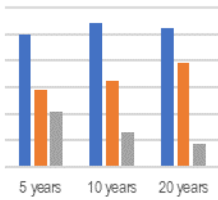
<td>
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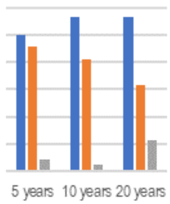
<td>
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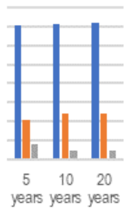
<td>
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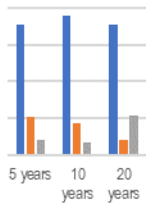
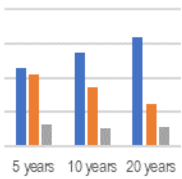
<td>
</td></tr>
<tr><td>Chi-square</td><td>16.21***</td><td>1.75</td><td>3.40</td><td>5.72</td><td>0.74</td><td>9.79**</td></tr>
<tr><td>Cramers V</td><td>0.21***</td><td>0.07</td><td>0.10</td><td>0.13</td><td>0.05</td><td>0.16**</td></tr>
<tr><td></td><td>Natural forests</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Highest proportion of change</td>
<td>
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Chi-square	3.83
Cramer s V	0.10

Participants in Keiskamma and Letaba catchments perceived that most of the observed changes occurred more than 10 years ago whilst participants in the Mthatha catchment believed that most of the observed changes happened more than 20 years ago. These views are important as they indicate participant awareness of land use changes. Awareness is a key factor in the identification, formulation, and implementation of associated mitigation strategies

The results shown in Table 5.1 reveal the perceptions of sampled participants on the changes per land use activities as well as changes recorded on the satellite. Most participants (90%) in the Mthatha Catchment perceived that built up areas had increased relative to the other land uses. Satellites image results also concurred with this view but recorded a 20-year increase of 0.5% in the built-up area. With regards to bare lands, sampled participants perceived a decrease (72%) in contrast to an observed 11% increase through satellite imagery in the Mthatha catchment. Participants in the Mthatha catchment also perceived decreases in cultivated land (77%), water bodies(56%), plantations (72%), grasslands (52%) and natural forests (59%).

In the Keiskamma catchment, participant perceptions concurred with satellite imagery observations except for waterbodies and plantations which were perceived to be on the decrease and no change respectively yet observed to be on the increase. Additionally, participants perceived that built up areas (47%) experienced an increase as also observed on the satellite image. However, according to satellite imagery, Keiskamma experienced a relatively higher increase in built up area (3%) as compared to the Mthatha catchment (1%). Participants perceived that bare surfaces were on the increase, yet satellite imagery revealed a 3% decrease.

Results shown in Table 5.11 also revealed the perception of sampled participants on land use change per category for Letaba catchment. Participants in the Letaba catchment perceived that cultivated areas and built-up areas experienced increases whilst the rest experienced no changes. All the perceived changes were misaligned with changes observed through satellite imagery except for the built up area. Of interest is the perception that no change was happening to plantations, water bodies, bare surfaces, grasslands and natural forests and yet increases (about 2%) were observed on the satellite images in the Letaba catchment. An increase in built up areas was experienced across the three catchments.

Table 5.11: Perceptions on land use change per category

Keiskamma Catchment	Land use type	Increase	Decrease	No change	Satellite Images
	Cultivated lands	25.1	61.8	11.5	Decrease (-0.14%)
	Built up areas	47.1	8.9	8.9	Increase (2.84%)
	Water bodies	13.1	25.1	16.8	Increase (1.11%)
	Bare surfaces	31.9	15.4	16.5	Decrease (-3.32%)
	Plantations	19.9	14.7	23	Increased (1.56%)
	Grasslands	47.1	20.9	11	
	Natural forests	36.6	17.3	24.0	
Letaba Catchment	Cultivated lands	70	11	18.9	Decrease (-0.14%)
	Built up areas	78.9%	3.3%	17.8	Increase (2.84%)
	Plantations	11.1%	44.4%	74.4%	Increased (1.56%)
	Water bodies	8.9%	36.7%	54.6%	Increase (1.11%)
	Bare surfaces	5.6%	25.6%	68.9%	Increased (1.56%)
	Grasslands	11.1%	26.7%	62.2%	
	Natural forests	22.2%	31.1%	66.7%	
Mthatha Catchment	Cultivated lands	16.9%	77.0%[a]	6%	Decrease* (-3.08%)
	Built up areas	90.7%	3.8%	5.5%	Increase

					(0.52%)
	Water bodies	8.2%	55.7%	36.1%	Decrease (-3.65%)
	Bare surfaces	4.9%	71.4%	23.6%	Increase (11.72%)
	Grasslands	15.8%	72.1%	12%	Decrease (-5.60%)
	Plantations	11.5%	52.5%	36.1%	
	Natural forests	11.5%	59%	29.5%	

The results in Table 5.12 below demonstrate the perception of perceived drivers and underlying causes of land use change in the three catchments. In the Mthatha catchment, the majority reported (91%) as the most important driver of land use change, followed by lack of financial resources (90.2%), poverty (89.1%), and new residential areas (88.5%). In Keiskamma, many respondents indicated land use policies (80%) as important towards changing the land use, followed by a lack of financial resources (86%), new residential areas (78.0) and an increase in livestock numbers (77.0%). In Letaba, most of the respondents cited population growth (80.0) as the most important factor in changing land use, followed by harvesting of fuelwood and agricultural expansion, with an equal number of respondents (63.3%), and poverty (57.8%).

Table 5.12: Perceptions of proximate and underlying drivers of land use change

Mthatha			
Drivers of land use	**Least important**	**Important**	**Most important**
Natural resource harvesting/firewood	65.6	11.5	23
Timber harvesting	47.5	25.8	25.7
New residential areas	4.4	7.1	88.5
Farm abandonment	17.5	6.6	76
Agricultural expansion	82	10.4	7.7
Increase in livestock numbers	36.6	36.6	26.8
Infrastructure development	19.7	23	57.4
Poverty	2.2	8.7	89.1
Lack of financial resources	1.6	8.2	90.2
Population growth	2.7	6	91.3
Lack of law enforcement	35.5	29.5	35
Land use policies	65.6	31.1	3.3

Demand for wood products	47.5	33.3	19.1
Lack of environmental awareness	59	10.4	30.6
Climate Change	3.8	11.5	84.7
Keiskamma Catchment			
Drivers of land use	**Least important**	**Important**	**Most important**
Natural resource harvesting/firewood	27.7	42.9	24.6
Timber harvesting	19.4	73.8	1
New residential areas	8.9	78.0	8.9
Farm abandonment	22	73.3	0.5
Agricultural expansion	19.4	76.4	0
Increase in livestock numbers	18.3	77.0	0.5
Infrastructure development	19.4	76.4	0
Poverty	19.4	72.8	3.7
Lack of financial resources	11.5	80.6	7.9
Population growth	17.3	71.7	6.8
Lack of law enforcement	15.7	73.3	6.3
Land use policies	6.3	83.2	6.3
Demand for wood products	13.6	73.8	7.8
Lack of environmental awareness	19.4	71.7	4.7
Climate Change	20.9	67.5	7.3
Letaba Catchment			
Drivers of land use	**Least important**	**Important**	**Most important**
Natural resource harvesting/firewood	27.8	8.9	63.3
Timber harvesting	67.8	8.9	23.3
New residential areas	25.6	21.1	53.3
Farm abandonment	-	-	-
Agricultural expansion	20.0	16.7	63.3
Increase in livestock numbers	-	-	-
Infrastructure development	54.1	24.4	21.1
Poverty	23.3	18.9	57.8
Lack of financial resources	32.2	22.2	45.6
Population growth	10.0	10.0	80.0
Lack of law enforcement	44.4	25.0	30
Land use policies	45.6	30	24.4
Demand for wood products	-	-	-
Lack of environmental awareness	-	-	-

The demand for new residential areas, farm abandonment, population growth, poverty, lack of financial resources and climate change emerged as the main drivers of land use change in the Mthatha catchment with approximately 90 per cent of the respondents ranking them as key drivers. Despite the Mthatha catchment being mostly rural, a higher proportion of the respondents perceive agricultural expansion (82%), natural resource harvesting (65.6%), land use policies (65,6%), lack of environmental awareness (59%), demand for wood products (47.5%) and lack of law enforcement (35.5%) as less important in driving land use change.

In contrast to the Mthatha catchment, the respondents in Keiskamma perceived all the drivers to be of importance and did not clearly categorise any as either most important or least important. Lack of financial resources (83%) and land use policies (81%) were ranked the highest. On the contrary, timber harvesting (68%), infrastructure development (54%) and land use policies (45%) emerged at the top of the least important driver of land use change in the Letaba catchment.

Population growth (80%), agricultural expansion (63%), natural resource harvesting (63%), poverty (58%) and new residential area (53%) were identified as the most important drivers of land use change in Letaba catchment. Across the three catchments, population growth emerges as a key important driver of land use change.

5.4.3 Mitigation and adaptation strategies

There were common responses concerning what the respondents perceived needed to be done to address the issue of land use change across the catchments. These were centred around the lack of enforcement by relevant authorities. In terms of recommendation, the majority across the catchment felt some form of education is needed for the public to be aware of aspects pertaining to land use change

"*Law enforcement needs to be increased*".
"*Police need to arrest people who take up land by force*".
"*People just cut trees*".
"*Education, environmental awareness and enforcement of rules*"
"Having law enforcement officers to guard the use of natural resources".
"*Creation of jobs*"

The quotes/responses above demonstrate that land use change is an important issue across the catchment communities with enforcement of rules seen as key to addressing it. However, not only is the enforcement of rules associated with harvesting of resources was perceived to be crucial but also those that relate to land allocation for new settlements as the community expand. In terms of strategies, some of the participants felt that education and awareness around land use change. In the Keiskamma catchment, for instance, lack of environmental awareness was reported to be one of the important drivers in land use change, contrary to the Mthatha catchment. This indicates that there are different perceptions in terms of environmental awareness across the catchments indicating that any intervention towards resolving land use change problems should take note of this. However, with more awareness regarding the linkage or relationship that land use change has on, e.g. the changing climate, people can reduce activities that contribute to land use and climate change as they are more aware of the latter. Job creation was another strategy that was recommended as key to reducing land use change. From the data, this relates to lack of financial resources and poverty, both of which were perceived to be among the top four reasons behind the changing of land use. This is clear because most of the people in rural areas harvest firewood because they cannot afford to cook with electricity but can with a stable income especially as most have access to electricity but limit its usage to light appliances.

5.5 Conclusion

This study established the status quo of the economic and social drivers of land use and land use cover (LULC) changes in the Letaba River Catchment (Limpopo province), Mthatha catchment, and Keiskamma catchment (Eastern Cape) using a systematic literature review, satellite images, cross-sectional surveys and focus group discussions. In the Mthatha Catchment, these include studies which spanned over a period of 21 years showing Land tenure and human settlement policies, migration, urbanisation and population growth as key underlying drivers of land use change. Similarly, population growth was identified by studies as one of the underlying drivers of land use change in the Letaba Catchment with poverty, use of land for agriculture and grazing. In the Keiskamma Catchment and the coastal areas, the underlying causes included port development and the provision of amenities. Results from this survey concur with the findings from the literature that LULC has been changing over the past 20 years but there were mixed perceptions across the catchments about when the most change has happened. An increase in built-up area was reported from the sampled households across the three catchments concurring with the satellite images. There was an observed incidence of convergence of literature review findings, respondents' perceptions and actual LULC changes as observed from satellite images and some incidence of disagreement. There was significant convergence of perceptions about the most important drivers of LULC across the three catchments. The demand for new residential areas, farm abandonment, population growth, poverty, lack of financial resources and climate change emerged as the most important drivers of land use change while land use policies, law enforcement and lack of awareness were ranked as least important. Respondents across all three catchments concur that education and awareness on land use and enforcement of rules against the harvesting of resources and improper land allocation are key to ameliorating the land use change problem.

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Chapter 6: Capacity Building

6.1 Abstract

Building the capacity of postgraduate students and academic staff is important in developing new and upcoming researchers and can contribute to national developmental goals. Strong postgraduate participation in the LULC research in the three catchments has the potential to strengthen the academic, research and community engagement programmes of participating universities through a suite of integrated, multi-disciplinary research approaches, which will ultimately lead to significant societal impacts and rural community benefit. In this LULC research project, two Doctoral students and four MSc students were supported. Two MSc students successfully completed their programme and the remaining students are all scheduled to complete in the 2023 academic year. The delay in successful completion was primarily due to the challenges caused by the COVID-19 pandemic restrictions.

6.2 Introduction

This report pertains to capacity building for the project, Earth observation and in-situ assessment of the impacts of land use and land cover changes on water quality and quantity in key water resources of Limpopo and the eastern cape, South Africa. The Water Research Commission (WRC) awarded the project to the University of Limpopo (UL), the lead institution, Walter Sisulu University (WSU), the University of Fort Hare (UFH) and the University of the Western Cape. The project commenced on 1 April 2020 and will run until 31 March 2023.

Bursaries have been awarded to four postgraduate students across the three universities to participate in the project, which is divided as follows: One MSc and one PhD from UL, one MSc from UFH, and one MSc from WSU. There is also a PhD student at the University of Fort Hare and one MSc student from ULF who did not receive direct funding from the project but conducted their research on some of the objectives of the project. The report focuses on the progress made thus far in enrolling students in graduate programs at their respective universities. This report is also a continuation of the previous report which is attached as an appendix.

6.3 List of registered students

The table below shows the list of students trained under this project.

Institution	Name	Degree	Citizen	Gender	Status
UL	Mashala Makgabo Johanna	PhD	South African	Female	Registered in 2021
UL	Lekganyane Mmamare Alice	MSc	South African	Female	Registered in 2021
UFH	Tonisi Nandipha	MSc	South African	Female	Registered in 2020
WSU	Ntlangula Sinawo	MSc	South African	Male	Registered in 2020
UL	Ntuli Hlengiwe Innocentia	MSc	South African	Female	Registered in 2021
UFH	Siphamandla Nyambo	PhD	South African	Female	Registered in 2020

6.4 Study progress

6.4.1 University of Limpopo

Student: Mashala Makgabo Johanna, PhD. University of Limpopo

Research Title: Understanding land use and land cover dynamics and their effects on the surface water resources at Letaba catchment, South Africa

Study Status	In progress
Study Objectives	• To map long-term spatial and temporal" changes of LULC within the Letaba watershed. • To map surface waterbodies found within the Letaba catchment using multi-source remotely sensed data. • Estimate the "effects of land use/cover on the water quality using the in-situ and remotely sensed data." • To determine the catchment ecological condition based on riparian vegetation community.
Progress to date	• Proposal approved by the School Higher Degrees Committee. • Done with the literature review • Objective 1 is revised following comments from reviewers and is submitted to a journal for publication. • The thesis write-up is ongoing
Activities in progress	• In-depth analysis of the available water bodies • Analyses of water quality data • Objective 2: mapping surface water bodies found within the catchment using multi-source remotely sensed data. • 5th National Global Change Conference presentation in Bloemfontein.

Remaining work to be done	• Data collection on water quality • Objective 3: estimate mapping the effects of land use and land cover changes on water quality and quantity using in-situ and remotely sensed data • Objective 4: to determine the catchment ecological condition based on riparian vegetation • Full data analyses and write-up.
Challenges that have arisen	• No significant challenges except the earlier Covid-19 regulations restriction and delays in the release of funds by the UL Finance Department.
Expected date of completion	• October 2023.

Student: Ntuli Hlengiwe Innocentia. MSc University of Limpopo

Research Title (Provisional): Variation in soil carbon storage and emission in different landuse systems of the Letaba Catchment, Limpopo Province.

Study Status	In progress
Study Objectives	• Determine the variation in soil CO_2 emission and soil carbon storage under different land use systems. • Determine the effect of land use system on selected soil properties. • Characterise the microbial decomposer communities in the different land use systems and determine their impact on CO_2 emission. • Determine the major soil factors driving CO_2 release in the different land use systems.
Progress to date	• MSc taught courses completed. • The proposal has been successfully defended at Department and School levels. • The proposal is provisionally approved by the Faculty Higher Degrees Committee • Soil samples have been collected and analysed for chemical and physical properties • CO_2 data collection has been completed • Soil sampling for microbial analysis has been completed • Data for CO_2, soil physical and chemical properties have been analysed
Activities in progress	• Microbial analysis at the laboratory is completed. • Treatments' effect on microbial data analyses is underway. • Writing of a draft mini-dissertation is in progress.
Remaining work to be done	• Completion of data analysis and mini-dissertation.

Challenges that have arisen	• No major challenge at this stage.
Expected date of completion.	• Completed. Will graduate in April 2023.

Student Lekganyane Mmamare Alice, MSc. University of Limpopo

Research Title: An evaluation of community perception of the Greater Letaba River as a source of sustainable livelihoods for the community of Mariveni, Limpopo Province.

Study Status	In progress
Study Objectives	• To explore how community members view the Greater Letaba River as a resource. • To explore changes in water quality and quantity. • To identify factors affecting the river's water quality according to community members. • To examine the socio-economic impact of polluted water on the community. • To examine how pollution affects the sustainability of the river as a resource.
Progress to date	• The proposal has been approved by the School Higher Degrees Committee (SHDC) on 4 November 2021. • The student has submitted the first draft of the Literature Review chapter. • Ethical clearance application submitted by the student on 19 May 2022-07-29 • Ethical clearance was granted on 15 July 2022. • A submission to the Faculty Higher Degree Committee (FHDC) on 28 January 2022. • A questionnaire developed is developed for data collection. • Data collection and capturing completed.
Activities in progress	• Literature review. • Data analysis.
Remaining work to be done	• Write up of mini dissertation and submission for external assessment. • Preparation of manuscript and submission for publication.
Challenges that have arisen	• No major challenges at this stage.

Expected date of completion.	• Graduation in September 2023.

6.4.2 University of Fort Hare

Student Tonisi Nandipha, MSc. University of Fort Hare

Research Title: An analysis of socio-economic factors that influence land use change (cultivated and build-up areas): The Case of Keiskamma catchment, Eastern Cape, South Africa

Study Status	In progress
Study Objectives	• To assess and estimate land use changes (cultivated and build-up area) from the study area. • To assess households' perceptions of land use change with reference to cultivated and build-up areas. • To estimate socio-economic factors that influence change in cultivated land within the study area. • To estimate socio-economic factors that influence change in built-up areas within the study area.
Progress to date	• Proposal submitted to the Higher Degrees committee. • Questionnaire is developed • Ethical clearance has been obtained • Data collection completed • Dissertation is completed
Activities in progress	• Data analysis • Submitted the first draft thesis for assessment • Supervisors have scheduled to submit the thesis to external examiners by the end of September 2022. • MSc programme completed
Remaining work to be done	• Awaiting graduation

Challenges that have arisen	• No major challenges at this stage.

Student: Siphamandla Nyambo, PhD, University of Fort Hare

Research Title: Modelling land use impacts on nutrient cycling and greenhouse gas emissions in ecotopes of Eastern Cape South Africa

Study Status	In progress
Study Objectives	• To assess farmers' perceptions of land use management practices on soil quality in the Raymond Mhlaba municipality. • To quantify the CO_2 emissions under different land use management practices in Raymond Mhlaba municipality. • To determine the effect of different land use management practices on soil hydraulic properties in the Raymond Mhlaba municipality. • Modeling long-term soil nutrient cycling and potential carbon sequestration in different land use management practices in Raymond Mhlaba municipality
Progress to date	• Chapters 1 to 4 completed (Introduction, literature review, methodology and study area) • Ethical clearance certificate application has been made, currently awaiting the certificate • Objective 1 data collection and analysis completed.
Activities in progress	• Publication writing objective one manuscript. • Data collection for the soil hydraulic properties • Data analysis
Remaining work to be done	• Carbon dioxide emission measurements.
Challenges that have arisen	• Lack of interest from most of the smallholder farmers in Raymond Mhlaba municipality. • LICOR carbon dioxide analyser broke down in the middle of emission collection. This caused some delays.
Expected Date of completion	• December 2023

6.4.3 Walter Sisulu University

Student Ntlangula Sinawo, MSc. Walter Sisulu University

Research Title: Socio-Economic Drivers Of Land-Use/Land-Cover Change Along With The Mitigation And Adaptation Strategies: A Case of Mthatha River Catchment

Study Status	In progress
Study Objectives	• To profile LULC along the Mthatha river catchment. • To determine the proximate and underlying socioeconomic drivers of LULC changes along the Mthatha River Catchment. • To identify the mitigation and adaptation strategies employed to address the challenges of land use/land cover change.
Progress to date	• The introduction, literature review and methodology have been completed • The description of the study area has been completed • Preliminary findings for the first and second objectives, that is, the profile of LULC along the Mthatha river catchment and the perceived proximate and underlying socioeconomic drivers of LULC changes are complete.
Activities in progress	• Currently, data collection through questionnaires, to complete the remaining objectives is underway.
Remaining work to be done	• Completing the dissertation.
Challenges that have arisen	• No major challenge. The initial challenge of releasing full funds to the student has been addressed.
Expected date of completion.	• The student is expected to complete her programme in March 2023 and graduate in September 2023.