AN INVESTIGATION AND ANALYSIS OF THE IMPACT OF THE WATER MANAGEMENT INSTITUTIONAL CHANGE ON THE WATER QUALITY OF THE KAT RIVER, EASTERN CAPE, SOUTH AFRICA

A Dissertation

by

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ABSTRACT

In 2001, the water management responsibilities in the Kat River, Eastern Cape, South Africa were transferred from the Kat River Irrigation Board to the Kat River Valley Water Users Association (KRVWUA). The impact this institutional change may have on the quality of the Kat River water is not yet quantified, and is therefore unknown. This study therefore investigates the impact of the KRVWUA on the salinity and nutrient status of the Kat River in the first decade since its establishment. To realize this aim: i) the extent of land use and land cover (LULC) change between 2001 and 2011 was assessed, and ii) it was established whether there has been a statistically significant change in the salinity and nutrient status of the Kat River basin during the 2001-2010 decade compared to the 1991-2000 decade.

The pixel-based supervised classification method was used with the minimum distance algorithm to classify land use from the 2001, 2007, and 2011 2.5m SPOT HRG satellite images. The extent of LULC changes was detected using the post-classification change detection technique. The images extracted from each satellite image were cross-tabulated with each other to establish the spatial distribution of the LULC classes using the cross-tabulation module in Idrisi Taiga. Results of this LULC study indicate that 30.5 percent of the study area was subjected to LULC change between 2001 and 2011.

Also, a paired-samples t-test was conducted to compare the nutrients and salinity variables' means of the two decades of a 20-year water quality dataset (1991 – 2000 and 2001 – 2010). Statistically significant differences ($\alpha = 0.05$) were observed as follows: in the Kat Dam site, increases in calcium, potassium, ammonium, nitrate, and chloride; in the Balfour River site, decreases in calcium, chloride, electrical conductivity, sodium, sulphate, and pH.

The following actions are therefore recommended in the upper catchment: that strong runoff controls be put in place, that animals be kept off the river, that environmentally

friendly toilet systems replace those in use, that more environmentally friendly conservancy tank systems replace the septic tanks, and that both conservancy tanks and graveyards be relocated away from the stream course.

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NOMENCLATURE

KRVWUA	Kat River Valley Water Users Association
LULCC	Land Use Land Cover Change
SPOT HRG	SPOT High Resolution Geometry
DWAF	South African Department of Water Affairs and Forestry (the old)
NWA	South African National Water Act No. 36 of 1998
ICM	Integrated Catchment Management
DWA	South African Department of Water Affairs
KRVCMF	Kat River Valley Catchment Management Forum
WUA	Water Users' Association
SAWRC	South African Water Research Commission
HACOP	Hertzog Agricultural Cooperative
NPS	Non-point source
LULC	Land use/land cover
IGBP	International Geosphere-Biosphere Programme
WCED	World Commission on the Environment and Development
SWAT	Soil and Water Assessment Tool
ET	Evapo-transpiration
HRS	High Resolution Stereoscopic
DTM	Digital Terrain Model
DEM	Digital Elevation Model
UTM	Universal Transverse Mercator
WGS	World Geodetic Systems
RMSE	Root Mean Square Error

USDA	United States Development Agency
GPS	Global Positioning System
FC	Fecal Coliform
DEIC	Dutch East India Company
RQS	Resource Quality Services
ADM	Amathole District Municipality
KATCO	Kat River Citrus Cooparative, Ltd.
BMP	Best Management Practices
EQS	Environmental Quality Services

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CHAPTER I

GENERAL INTRODUCTION

1.1 Background

Since the advent of democracy in South Africa, the country has experienced a complete paradigm shift in the management of its water resources (Hebertson and Tate, 2001). The Water Act 54 of 1956 (Water Act) favoured the economic heavy weights in agricultural, mining, and industrial sectors to the detriment of the ordinary citizens of the country (Tewari, 2009). Most harmed by the Water Act were the black African communities who were denied access to land. Because the Water Act was heavily based on riparian principle, by implication, those without access to land could not have access to water either (DWAF, 2004; Tewari, 2009).

In its quest to redress the harm caused by the apartheid regime, the democratic government of South Africa deemed it imperative to adopt new approaches and strategies when it got into office in 1994. This was in view of the fact that, according to Livingstone (2005: 21), '…the allocation and use of water resources are often critical to achieving specific regional and national goals including efficiency, equity and overall social welfare'. A new legislation [National Water Act No. 36 of 1998 (NWA)] was introduced to replace the Water Act of 1955. While the Water Act was based on supply management, NWA is heavily entrenched on the principles of conservation and demand management (Le´vite *et al*. 2002).

NWA is driven by the principles of an integrated catchment management approach in managing the country's water resources [South African Department of Water Affairs and Forestry, (DWAF) 2004; National Water Act No. 36 of 1998)]. The Integrated Catchment Management (ICM) is defined as: 'a systems approach to the management of natural resources, in particular water resources, within the bounds of a geographical unit which is based on the catchment area of a single river system' (DWAF, 1996: 19-20).

The ICM approach to catchment management is integrative of all environmental, economic, and social issues within a catchment (DWAF, 1996). The end result is the management philosophy which takes into account the needs of all stakeholders. The resultant catchment management plans, processes, and actual management activities are holistic in nature (DWAF, 2004). DWAF (2004) further documents that, such plans involve all community members, individuals, farmers, cooperatives, municipalities etc. who have a genuine interest in a particular river system.

In view of the above background, it was also crucial that the institutions entrusted with the responsibility of actual managing an individual river system be transformed. Livingstone (2005) seem to affirm this view by articulating the necessity to change the water institutions given a change in the nation’s economic, social, political, and physical circumstances. This is in view of the recognition of the pivotal role these institutions play in a nation’s development and prosperity (Livingstone, 2005).

In South Africa, this change was first pronounced in DWAF (1996), a document of 28 principles that later informed the water management legislation that was to replace the Water Act. Principles 22-24 of that document provide guidance on the development of the new water institutions (Tewari, 2009). As a result, chapters 7-9 of NWA mandates the national minister of the Department of Water Affairs (DWA) to transform the exclusive irrigation boards into stakeholder-driven Water Users Associations, responsible for the management activities of a river system on a local scale on the one hand. On the other hand, the Catchment Management Forums serve as structures that provide an oversight management of the entire basin (DWAF, 1997; NWA, 1998; McMaster, 2002; Soviti, 2002; Tewari, 2009). The Kat River Valley Catchment Management Forum (KRVCMF) and the Kat River Valley Water Users Association (KRVWUA), established in 2001, were among the first to exist in the country (Soviti, 2002).

While the need for this change cannot be argued against, the impact it has had on the quality of the resource (water) is a reason for concern. Literature is replete with evidence of the negative impact of the change in water management institutions on the quality of water. This is in view of the challenges these new institutions are often faced with in their inception. For example, Bandaragoda (1999) identified two difficulties in Pakistan that hindered the functioning of the new institutions as follows: the first is the rigid legal framework that does not allow these organizations autonomy to function.

The second is the lack of will on the part of the politicians in government. Often, because of lack of financial support, most of these institutions fail to take off (Bandaragoda, 1999), and task/s they were mandated to carry out often remain in complete disarray. Like Bandagoroda, Fischhendler and Heikkila (2010: 1) also observed that 'efforts to adapt Israel's water management system to new conditions and uncertainties reveals that the interconnectedness of the system and the consensus decision-making process, led by a dominant actor who coordinates and sets the policy agenda, tends to increase the complexity of negotiations'. Fischhendler and Heikkila (2010) further noted the high cost of physical infrastructure that come as a consequence of the physical integration of water management as one of the factors hindering the functioning of the newly established institutions.

1.2 The problem statement

As was indicated earlier, in 2000/1, the water management responsibilities in the Kat River were transferred from the former predominantly white Kat River Irrigation Board to the newly-formed all-encompassing community-based Kat River Valley Water Users Association (WUA). The impact this institutional change may have on the quality of the Kat River water is not yet quantified, and is therefore unknown. What is required is the quantification of the impact of the institutional change in water management on the Kat River water quality. In this study therefore, the impact of the Kat River Valley Water User Association on the quality of the Kat River in the first decade since its establishment is investigated. Following therefore are the objectives of the study, and their related research questions:

1.3 Objectives

- assessing land-use change in the Kat River valley since 2001;
    - Has there been any noteworthy land-use change in the Kat River valley since 2001?
- examining the impact of institutional change on the salinity and nutrient status of the Kat River water;
    - Is there a significant difference in the salinity and nutrient status of the Kat River water before and after the establishment of the Kat River Valley Water Users Association?

1.4 Justification of the study

This study assesses the effectiveness of the Kat River Valley Water Users Association (KRVWUA) in managing the water resources of the Kat River. Water quality is used as an indicator. Chapters 7-9 of the South African National Water Act No. 36 of 1998 (NWA, 1998) assign the river basin management mandate and authority to the Water User Associations (at local level) and Catchment Management Agencies at catchment level, thus effectively replacing the former irrigation boards (Tewari, 2009). The Kat River Valley Water Users Association (KRVWUA) was established in 2000/2001, one of the very first in the country.

The study seeks to evaluate the effectiveness of the KRVWUA in managing the quality of the Kat River in its first decade of existence. The study will thus illustrate to the KRVWUA whether the quality of the river water is improving or depreciating since they (KRVWUA) took over basin management task from the irrigation board in 2001. In highlighting the nutrient enrichment and salinity challenges in the Kat River, the study seeks to inform the river basin management if such water quality components are a problem in the study area. The results of the study can also be used by other WUAs in agricultural catchments countrywide to better and more effectively manage the quality of water in their respective basins. The study will also assist the newly established WUAs in other rural basins to learn from the Kat River situation what to emulate or avoid in managing the water quality status of their respective basins.

1.5 Structure of the dissertation

This chapter (Chapter 1) is a general introduction to the study. A brief description of the study area is presented in a chapter that follows (chapter 2). In Chapter 3, an assessment of the extent of land use/land cover change (LULCC) between 2001 and 2011 in the Kat River Valley is presented. Chapter 4 presents the results of an investigation and analysis of the impact of the water management institutional change on the water quality of the Kat River. Chapter 5 is the concluding discussion, bringing to close to the entire study, assessing whether the objectives of the study have been realized, and also presenting recommendations in view of the findings of the study.

CHAPTER II

DESCRIPTION OF THE STUDY AREA

2.1 The geographic location of the Kat River valley

The Kat River originates from the Amatole Mountains through Seymour and Fort Beaufort (Figure 2.2), and joins the Great Fish River south of Fort Beaufort. This study zooms into the segment of the river between Seymour in the upper reaches and Fort Beaufort in the lower middle reaches (Figure 2.1).

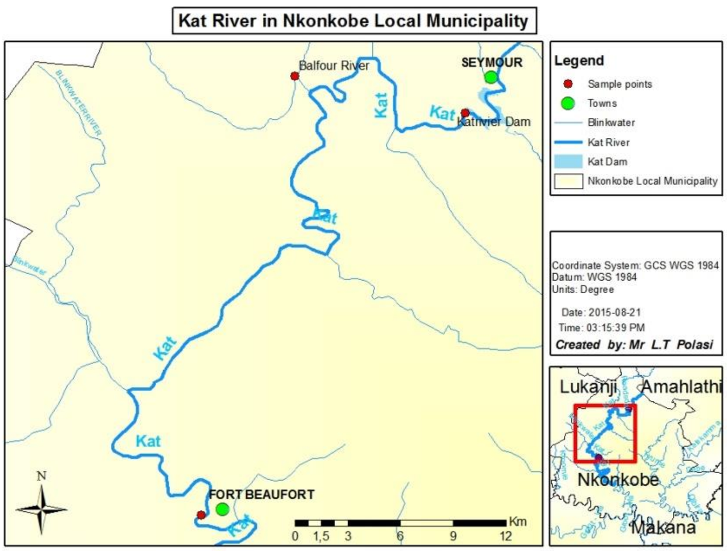

Figure 2.1: The study area

The Kat River valley is in the Nkonkobe local municipality. Nkonkobe is one of the seven local municipalities forming the Amathole District Municipality (The Local Government Handbook, 2016). The other six are identified in the Local Government Handbook (2016) as follows: Mbhashe, Mnquma, Great Kei, Amahlathi, Ngqushwa and Nxuba (Figure 2.1).

Figure 2.2: The seven local government municipalities forming the Amathole District Municipality

Amathole District Municipality, within which the study area lies is one of the six district municipalities in the Eastern Cape province of South Africa (Figure 2.2). The other five being: the O.R. Tambo shares the north-east border with Amathole; and further north-east is the Alfred Nzo. Chris Hani is in the immediate north of the Amathole, whilst Joe Gqabi is further north. To the south of Amathole is the Sarah Baartman. The Buffalo City, one of the two metropolitan municipalities of the Eastern Cape is completely enclosed within Amathole Ditrict Municipality whilst the other, the Nelson Mandela Bay is inside Sarah Baartman.

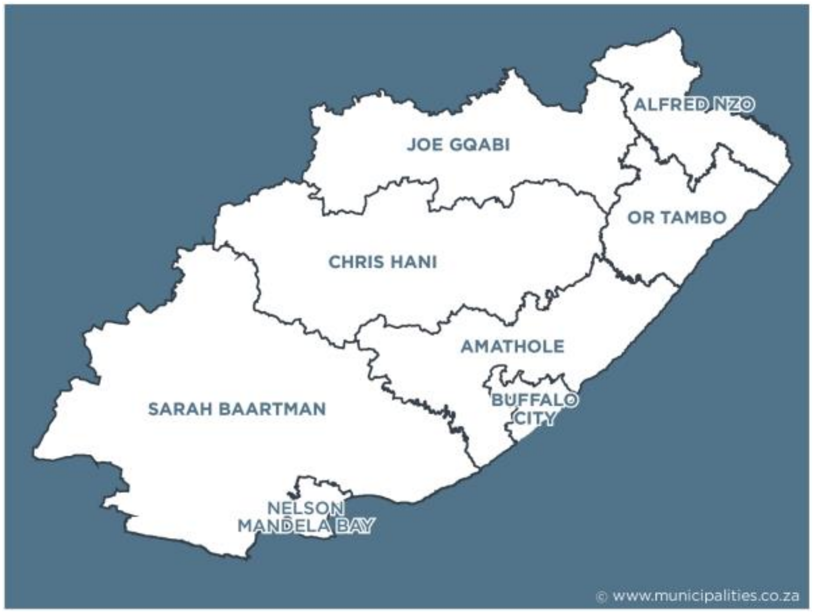

Figure 2.3: The district municipalities of the Eastern Cape Province, South Africa

Figure 2.4 shows the study area in relation to the four largest and most popular metropolitan cities of South Africa. Fort Beaufort is about 141 kms from the Buffalo City metropolitan area to the south-east (East London); 210 kms from the Nelson Mandela Bay (Port Elizabeth) to the south-west; 753 kms from eThekwini (Durban) to the further north-east; 900 kms from Johannesburg to the north; and 903 kms from Cape Town to the further south-west. The study area thus is located almost half-way inside the triangle of the three largest cities in South Africa: Durban to the north-east; Johannesburg to the north; and Cape Town to the south west.

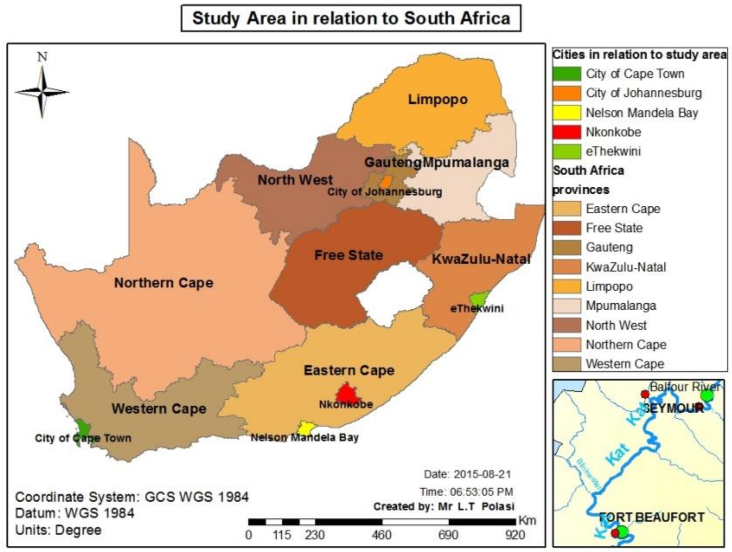

Figure 2.4: The study area in relation to the four largest metropolitan areas of South Africa

2.2 The biophysical characteristics

The climate of the study area is mild (Motteux, 2000). Summer temperatures vary between 20^0C and 35^0C . Winter temperatures vary between 0^0C and 20^0C (Schoombe *et al*. 1997). Annual average rainfall of the study area is 400mm in the immediate vicinity of Fort Beaufort and 1200mm in the upper Kat River area (Schoombe *et al*. 1997). The area receives most of its rainfall in the October/November and February/March periods (Schoombe *et al*. 1997). Rainfall received in the study area varies between low intensity-long duration and high intensity- short duration types (Schoombe *et al*. 1997). The area is also characterised by great variability of rainfall (Barrett, et al. 2001).

The altitude in the area ranges between 1600 metres at the source of the Kat River, which is the top of the escarpment, and 600 metres at the confluence with the Fish River (Geological Map of Southern Africa, 1970). The river valleys are deeply incised, and characterised by narrow alluvial terraces bordering the river (Barrett, et al. 2001). The vegetation is largely of the valley bushveld and river thicket type, although, at high altitudes, pockets of Afro-montane forest and grassland vegetation are evident (Motteux, 2000).

The study area's geology forms part of the Beaufort series of the Karoo system (Geological Map of Southern Africa). It belongs to the Molteno, Red Bed and Cave Sandstone Stages (Geological Map of Southern Africa). Dominant rocks include shale, mudstone, sandstone, and limestone (Geological Map of Southern Africa). According to Barratt (1998), geology affects the quality of water resources in a number of ways. These include the rate at which the river erodes and transports material along its course. In turn, erosion determines the amount of sediment available for transportation by the river, and hence its turbidity. Barratt (1998) further points out that, the type of rock structure over which the river flows may be one of the major sources of salts and metals in many river systems.

2.3 The historical background

Most of the area, especially in the upper and middle section of the basin belonged to the former Ciskei homeland government (Motteux, 2000). According to the Water Research Commission (WRC, 1997), this area falls into the Tsitsikama and Fish River Water Management Area. The Kat River falls within the primary catchment of the Fish River (WRC, 1997).

The farmlands in the area were used by White and 'Coloured' farmers, with tobacco, potatoes and citrus being the main agricultural products till the 1970s (Nel and Motteux, 1999; Motteux, 2000). The reliable flow of the Kat River, regulated by a dam since the 1970s, and fertile valley soils encouraged the practice of successful intensive irrigation farming (Motteux, 1999). The transference of the land to the Ciskei government led to the migration of White and Coloured communities out of the area (Nel and Hill, 1996).

As a result, African populations were adversely affected economically, as they were marginalized (Motteux, 1999). They lost their jobs, and were also denied access to any means of production in the area (Nel and Hill, 1996).

The government para-statal, Ulimcor took up some of the ex-white farms to provide farming assistance to support interested farmers in the Kat River (Nel and Hill, 1996; Nel and Motteux, 1999). These farms were transferred to Black emerging farmers to manage. Only these farm managers had the rights to use the land. According to Nel and Motteux (1999), some lands currently lie open with no land tenure. The exception in this instance is the Fairbairn area, in which some of the land has been privately owned since early 1900s. Part of the area was never transferred to the former Ciskei homeland, and has been under the commercial citrus farmers for generations (Mottex, 1999).

2.4 The service centers

In the former Ciskei area the town of Seymour and the semi-rural Balfour centre are the service centers. These are currently small, impoverished centers, suffering from a legacy of disinvestments, economic collapse, lack of political interest and endemic poverty (Nel and Motteux, 1999). In the remaining part of the study area, Fort Beaufort is the main service centre.

2.5 The key land-use practices

Most land in the valley bottom terraces is utilized for intensive crop farming purposes. HACOP Cooperate farming activities dominates the Fairbairn, and Hertzog areas. Citrus farming is mainly found in the middle Kat River valley, from the Upsher community to below the town of Fort Beaufort. Citrus farmers own the lands they are farming, but in most parts land is owned by the State but is occupied communally. Commercial Forestry is being practised in the upper Buxton River catchement. Mpofu Nature Reserve covers most of the middle Blinkwater River valley. Chapter 3 presents an in-depth analysis of land-use and its dynamics in the area between 2001 and 2011.

CHAPTER III

AN ESTIMATION OF THE EXTENT OF THE LAND USE/LAND COVER CHANGE BETWEEN 2001 AND 2011 IN THE KAT RIVER VALLEY, EASTERN CAPE PROVINCE, SOUTH AFRICA

3.1 Overview

This study quantifies land use and land cover change (LULCC) over a ten-year period (2001 to 2011) from the remotely-sensed data in a region that has been characterized by the inter-racial conflicts over the ownership of land through the centuries. The 2.5m SPOT High Resolution Geometry (HRG) satellite images of the study area for 2001, 2007, and 2007 were obtained from the South African National Space Agency. The pixel-based supervised classification method was used to classify land-use in the study area. The minimum distance algorithm was selected to perform classification. The post-classification change detection technique was applied to detect the extent of change in the Kat River Basin between 2001 and 2011. From each of the 2001, 2007, and 2011 2.5m SPOT HRG satellite images, a subset image covering the specific area under study was extracted. The images were cross-tabulated with each other to establish the spatial distribution of the land use/land cover (LULC) classes using the cross-tabulation module in Idrisi Taiga.

Results of this LULC study indicate a 12.6 percent increase in the area covered by Forestry in the Kat River valley between 2001 and 2011. Between 2001 and 2011, the area of Built Environment also increased by 3.3 percent. An area of Bare Surfaces also increased by 0.2 percent between 2001 and 2011. On the other hand, Commercial Citrus Farming decreased by 6.5 percent between 2001 and 2011. A similar trend is observed in the rangeland area. Between 2001 and 2011, rangeland decreased by 7.9 percent.

A concern exists that observed land use and land cover change in the Kat River valley may impact the natural environment. As noted in literature, water resources are particularly vulnerable to the land use change impacts. A water quality study to assess this impact is recommended.

3.2 Background

This chapter analyses land use and land cover change in the Kat River Valley between 2001 and 2011. This period marks the first 10 years of existence of the legislatively mandated in the South African National Water Act no. 36 of 1998 (NWA, 1998) of the Water Users Association (WUA). WUA is am integrating body formed by all individuals, communities, or bodies that have expressed an interest on a particular water body as stakeholders. In most agricultural basins in South Africa, WUA replaced the Irrigation Board. This study is part of a bigger study, seeking to establish whether the water quality of the Kat River Basin changed significantly since the establishment of the WUA in the Kat River Valley in 2001.

Berka *et al*. (2001) raised a concern about a challenge on how to manage the 'cumulative effect' of the non-point source pollution (NPS) occurring at different temporal and spatial scales. They pointed out that this challenge was more pronounced in areas of intensified agricultural (livestock and crop production) activities. In the case of intensified crop production, the problem was blamed on the higher loads of agro-chemicals (fertilizers, herbicides, pesticides etc.) applied on the crops (Berka *et al*. 2001). These often consequently result in the nutrient enrichment of the agro-chemicals on the aquatic environment as follows: fish die of ammonia poisoning; higher levels of nutrients in groundwater; and eutrophication, which, in turn diminishes the oxygen content sustaining aquatic life in that water body.

Cooper (1995) further suggested that, the microbial quality of the water body may be negatively impacted. This effect holds a potential for affecting the fitness of water from that water body for some uses. O'Connor and Kuyler (2009) compared the influence of the 10 different land use categories on landscape structure, functioning, and composition.

Their observations seem to indicate that, the land use categories of conservation, livestock ranching, game ranching, and tourism/recreation could be considered ‘biodiversity friendly. These land use categories had minimal impact on the biodiversity integrity (O’Connor and Kuyler, 2009). On the other hand, rural, dairy, dryland crops, irrigated crops, timber, and urban land use categories all reportedly had severe impact on the biodiversity integrity (O’Conner and Kuyler, 2009).

Literature evidence exists regarding the impact of LULCC on several parts of the natural environment, and on different scales. For example, Ojima *et al*. 1994 assessed the global impact of LULCC. They linked such global challenges as air pollution and global warming to the intensification of certain land use activities and the change in land cover in many regions globally. Ojima *et* al. (1994) refer to the earlier literature to illustrate further the global impacts of land-use/land cover change. For example, Turner, *et al*. (1993); (1990); Clark *et al*. (1986); Ehlich *et al*. (1977) blamed the modification of entire landscapes and altered plant and animal communities globally on agriculture, forestry, and other land-management practices. Clark *et al*. (1986) also blamed the global alterations to major biomes on land conversion for crop production. International Geosphere-Biosphere Programme (IGBP, 1990) and World Commission on the Environment (WCED, 1987) blamed the removal of indigenous species, introduction of exotic species, re-routing of hydrological flows, contamination of air and water on land use/land cover change resulting from human activities globally.

Islam and Weil (2000) assessed the effects of land use changes on soil quality properties in a tropical forest ecosystem of Bangladesh. The natural forest was being degraded, and being replaced with crop production. They observed surface compaction of the soils, and significant decreases in silt and clay contents, porosity and aggregate stability, N, fulvic and labile C, and microbial biomass C. They also noticed an increase in maintenance respiration rates, compared to the soils under natural forest. They further observed that, in land under cultivation, soil quality deteriorated by 44 percent. In the sites re-vegetated with Acacia grass, the quality of the soils improved by between 6 and 16 percent. The likely consequences of soil deterioration noted by Islam and Weil (2000) include: increased disruption of macro-aggregates; reductions in microbial biomass; and loss of labile organic matter due to fire, deforestation, tillage and accelerated erosion. On the other hand, the improvement in soil quality may be an indication of the resilience of the soils in re-vegetated sites.

In a later study, Emadi *et al*. (2009) examined how land use change affects the soil fertility properties within water-stable aggregates of the two cultivated soils in northern Iran. They thus compared the distribution of the nutrients and carbohydrates within such soils. They established that the mean weight diameter and water-stable aggregates were bigger in the forest and pasture lands than the neighboring cultivated lands. Emadi *et al*. (2009) also observed that, the virgin forest and grasslands were significantly richer in organic carbon, nitrogen, phosphorus, and carbohydrates than the exposed cultivated lands. Overall, Emadi *et al*. (2009) observed that, the conversion of the forest and grass lands into cultivation lands resulted to the significant reduction in the nutrient content of these soils.

Scanlon *et al*. (2005) established how the conversion of natural rangeland ecosystems to agricultural systems affected the groundwater recharge, as well as the flushing of salts to underlying aquifers in the southwestern US. Results of their study indicated a good correlation between the groundwater recharge and land use/land cover as follows: ‘discharge through evapo-transpiration in natural rangeland ecosystems (low matric potentials; high chloride and nitrate concentrations); moderate-to-high recharge in irrigated agricultural ecosystems (high matric potentials; low to moderate chloride and nitrate concentrations); and moderate recharge in non-irrigated (dryland) agricultural ecosystems (high matric potentials; low chloride and nitrate concentrations, and increasing groundwater levels). Replacement of rangeland with agriculture changed flow directions from upward (discharge) to downward (recharge).

Schilling *et al*. (2008) used the Soil and Water Assessment Tool (SWAT) to evaluate three varying primary LULCC scenarios in the Racoon River Basin in United States Corn Belt. The scenarios evaluated were: an expansion of corn acreage in the watershed and the two scenarios involving expansion of land using warm season and cool season grasses for ethanol biofuel. The SWAT results indicated that, varying scenarios may affect the water balance in the basin differently. Specifically, Schilling *et al*. (2008: 1586) predicted that, an increase in corn production may lead to a 'decrease annual ET and increase water yield and losses of nitrate, phosphorus, and sediment'. They (Schilling *et al*. 2008) also noted that, an increase in the perennialization of the crops may 'increase ET and decrease water yield and loss of nonpoint source pollutants'.

Haynes and Michalek-Wagner (2000) attributed the elevated diuron, dioxins, dieldrin, mercury, and cadmium concentrations in the Great Barrier Reef in Queensland coastlines in Australia to the intensive cropping agriculture. Meybeck (2009) linked the instance of the 'progressive salinization' with sodium chloride and other dissolved salts in excess of 100 mg/l of the many streams in Australia to deforestation in those parts. Earlier, Allison *et al*.(2003) blamed the same factor for the increase by two orders of magnitude of the dissolved salt levels on the groundwater, following the clearing of the indigenous vegetation in the semi-arid part of Australia. From that observation, they predicted an increase in salinity levels of 1 µS per year on the groundwater in the area for the 50 years following the publication of their work (Allison *et al*. 2003).

This current study is conducted in view of the above-documented evidence implicating LULCC on degrading the natural, especially the aquatic environment. An earlier study (Soviti, 2002) linked land use to the land use and related practices in the upper part of the Kat River basin. Major land-use and related activities identified include settlements, cropland, grazing land, commercial citrus farming and commercial forestry. The water quality problems that were noted to result from rural land-use and related activities in the area included:

- the nutrient enrichment of surface water bodies leading to the eutrophication effect and health problems on those consuming the water, particularly infants and sensitive groups;
- pathogens being introduced into the aquatic systems thereby causing serious health problems like cholera outbreak on the communities consuming the polluted water.

3.3 Problem statement

In view of the literature evidence presented in section 3.1, LULCC have a potential to affect the quality of water of the surface water bodies and groundwater in the Kat River Valley. In view of that realization, and Soviti (2002)'s findings that the quality of water in the upper parts of the basin is being impacted by land use practices in the area, a concern exists that land use in the study area may be impacting the quality of the Kat River water. What is needed is thus a water quality study in the area to confirm or reject that concern. However, the study of the land use practices and the extent to which they have changed between 2001 and 2010 is required first. Through quantifying LULC and LULCC in the Kat River Valley from the satellite imagery, this study addresses that need. This study therefore quantifies land use and land cover change in the Kat River Valley between 2001 and 2011

3.4 Materials and methods

In this study, remote sensing approach is used to assess LULCC in the Kat River valley between 2001 and 2011. This methodology has been successfully applied in different environments to study land use/land cover change by many authors earlier. For example, Dewan and Yamagushi (2009) combined the remote sensing technique and GIS to assess the LULCC in the Greater Dhaka, Bangladesh between 1975 and 2003. Xiao *et al*. (2006) used GIS and remote sensing techniques to study the temporal and spatial attributes of urbanization of the Shijiazhuang city in China between 1987 and 2001. They reported an accuracy of the Landsat-derived LULCC that ranged between 85 percent and 90 percent. Stow *et al*. (2004) applied remote sensing to monitor vegetation and land cover change in the Arctic Tundra ecosystems.

3.4.1 Data sources and pre-processing

The 2.5m SPOT-5 High Resolution Geometric (HRG) satellite images of the study area for 2001, 2007, and 2011 were obtained from the South African National Space Agency. Launched on May 4th, 2002, SPOT-5 is the fifth satellite of the SPOT satellite series. It was launched to ensure that there is continuity both of data acquisition and space image services. Also, SPOT-5 was to ensure that users enjoy advanced products. The satellite was equipped with two identical cameras: a High Resolution Geometry (HRG), with a 2.5 m resolution, a 5 m resolution in panchromatic mode, and a 10 m resolution in a multi-spectral mode, while still keeping the 60 km ground field; and also a High Resolution Stereo (HRS) instrument.

The popularity gained by the SPOT HRG in the LULCC studies can be attributed to two reasons. First are the inaccuracies identified before the launch of SPOT-5. For example, a 1999 study pre-dating the launch of the SPOT-5 satellite, conducted by Mas highlighted the inaccuracies of most of the change detection procedures most commonly used at the time.

The benefit of high resolution derived from the SPOT HRG images has also led to their wide adoption and application. Because of its high resolution, the SPOT HRG is particularly suitable for the identification of features during the land use classification process, and the other subsequent data analysis stages. Lu *et al*. (2008) compared the accuracy of the Landsat TM and SPOT HRG images for classifying vegetation in the Amazon Basin, in Brazil. They observed an improvement of between 3.1 and 4.6 percent in vegetation classification accuracies when using SPOT HRG images. The observed improvement was however even higher (6.3 percent) when the HRG spectral signatures were combined with two spectral images.

So much is the wide adoption of the SPOT imagery that, their high resolution has been exploited in some other remote sensing applications as well, besides the LULCC. For example, Corbane *et al*. (2008) reports on an ‘algorithm for automatic ship detection from SPOT-5 HRG’. The purpose of this algorithm was to enhance the already existing fishery control measures in Europe. Through the application of this algorithm, the small targets like the shrimp boats were successfully classified from the panchromatic 5-m SPOT-5 imagery. Wallerman and Holmgren (2007) used the airborne laser scanning and SPOT HRG data to identify and estimate the field-plot data of forest stands. Toutin (2006) extracted the digital terrain models (DTMs) from SPOT-5 High Resolution Stereoscopic (HRS, 10m resolution) in-track stereo-images and High Resolution Geometric (HRG, 5m resolution) across-track stereo-images using a three-dimensional (3D) multisensor physical model developed at the Canada Centre for Remote Sensing, Natural Resources Canada.

It is in view of the advantages of the SPOT HRG images listed above that they were used in this study to assess LULCC. All images selected were acquired during the summer period (between October and February). This is also the wet season in the study area. Vegetation is thus green, and also, it is easier to distinguish between the spectral reflectances of forest land, citrus farms, rangeland, built environment, and bare surfaces. Images with more than 5 percent cloud cover were not included.

Also obtained from the South African National Space Agency (SANSA) were the higher resolution (5m) SPOT-5 HRG satellite images of the study area. The 1:50 000 topographic maps and aerial photographs, and the 20m DEM of the study area were obtained from the South African Department of Rural Development. All these data sets (2.5m SPOT-5 HRG Images, topographic maps, the 20m DEM, and aerial photographs) were used for assessing the accuracy of the results of the analysis of the 2.5m satellite images.

3.4.2 Image processing

From each of the 2001, 2007, and 2011 5m resolution SPOT HRG satellite images, a subset image covering the specific area under study was extracted. Ortho-rectification of the images was then conducted to correct different angles. This was done to ensure that each image overlayed correctly with other datasets. Images were georeferenced to a higher resolution (2m) spot mosaic of the study area. Each was then projected to the Universal Transverse Mercator (UTM) projection system. The World Geodetic Systems 1984 (WGS 1984), datum was used. Relief displacement was checked against and corrected using the 20m DEM of the study area. The cubic convolution resampling procedure was applied on each resampled image to enhance the geometric accuracy, as recommended by Campbell *et al*. (2002) . The procedure returned an RMSE of less than 023 pixels.

Equation 3.1 was used for the atmospheric correction of the satellite images as well as normalizing their reflectances.

Equation 3.1: Used for the atmospheric correction of the satellite images and normalizing their reflectances

$$Ry = PI * D * \frac{Ly - Ly.Haze}{Esun} * Cos(\theta)$$

For SPOT 4 HRG data, $Ly = DNy/Ay$

Where: $Ly = prenominal\ radiance\ for\ the\ spectral\ band$

$DNy = digital\ number\ of\ band\ y$

$$Ay = calibration\ factor\ for\ the\ image$$

$$Ly.Haze = path\ radiance$$

$$Esun = exo - atmospheric\ solar\ radiance$$

$$D = the\ distance\ between\ the\ earth\ and\ \theta, Zenith\ of\ the\ angle$$

The water bodies and shades on each image were used to identify radiance. This method had been successfully applied earlier (Lebreque, *et al*. 2006; Canty *et al*. 2004; Lu *et al*. 2002).

3.4.3 Definition of Land Use and Land Cover Classes

The LULC classification system adopted in the study is a modification of Anderson *et al*. (1976)'s. Definitions of the LULC classes are therefore similar to those of Anderson *et al*. (1976)'s. These are presented in Table 3.1. A modification made was that of adding a citrus farming class, instead of the general agricultural land class in Anderson *et al*.'s classification. This modification was made necessary by the prominence of the commercial citrus farming activity in the study area, and the observation that, there is very little other crop farming practiced. Also, all land use practices that are not in the study area were removed from the classification.

Table 3.1: Definition of LULC classes adopted in this study (adapted from USDA, 2012; Anderson et al. 1976)

Class	**Definition**
Water	For the purpose of this study, this class include streams and canals (all linear water bodies) and lakes (non-flowing naturally enclosed bodies of water)
Forest Land	'forest lands have a tree-crown areal density (crown closure percentage) of 10 percent or more, are stocked with trees capable of producing timber or other wood products, and exert an influence on the climate or water regime'.

Table 3.1: Continued

.Class	Definition
Citrus Land	Including the oranges, grapefruit, tangerines etc.
Built Environment	Land in this category is characterized by intensive use and dominated by the human-made structures. This class would include cities, villages, towns, strip developments along the highways etc.
Rangeland	In this class, natural vegetation is predominantly, grasses, grass-like plants, forbs, or shrubs, or brush-lands
Bare/Barren Surface	Vegetation covers only less than one third in this category. This is in view of the little ability of soils in this category to support life.

3.4.4 Classifying land use/land cover from the images

As was noted earlier, the pixel-based supervised classification method was used to classify land-use in the study area. As recommended by Matinfar *et al*. (2007), the classification procedure followed the three basic steps, as follows:

3.4.4.A Selecting the Training Samples

For the 2001, and 2007 satellite images, this involved identifying prominent features for each land use/land cover class from the satellite imagery that existed in those years that could be easily identified on the ground. These were used as reference points for comparison of land use practices around these reference points between 2001, 2007, and 2011

Field surveys were then conducted in the study area between August 2011 and December 2011 during which, a centimeter level precision GPS was used to confirm the reference points collected from the 2001 and 2007 images. As was noted earlier, land use around each of these reference points was studied and compared between 2001, 2007, and 2011 land use conditions to establish if land use practices around these reference points has changed over the years. During the 2011 field surveys, a sample geographic coordinates were collected from each land use category for 2011. 50 reference points were collected from each land use/land cover class. Thus, a total of 300 points were collected. The coordinates were randomly collected from several locations of each of the six land use classes adopted in this study. Careful consideration was put into the effort of collecting the GPS coordinates to ensure that, the points collected were representative of and typical for that land use class. These homogenous surfaces were then identified in the image to form the training samples for all land use classes. The points were then imported into ArcGIS 10 where they were converted into shapefiles, before exported to Idrisi Taiga. They were then overlaid with each satellite image for extraction of the pixels.

3.4.4.B Performing Classification

Classification of LULC classes was conducted in Idrisi Taiga. The supervised minimum distance algorithm was selected to perform classification. Matinfar *et al*. (2007) explain how this algorithm works as follows: first, the mean spectral value of each band for each land use category is determined. A distance threshold is then computed for each class. The threshold value may vary from class to class. A pixel further than the defined threshold for a particular class from the class mean may be classified as "unknown". Compactness is then approximated from the standard deviation 'for each feature of pixels making up training sample for a given class' (Matinfar *et al*. 2007: 3).

3.4.4.C Assessing Accuracy

From each LULC map generated (2001, 2007, 2011), 500 pixels were sampled using the stratified random sampling. The thematic accuracy of these was checked against the aerial photographs, and topographic maps of the study area. Soviti's (2002) and McMaster's 2002 studies that were conducted in the study area were also used to assess the thematic accuracy of some features. The content accuracy of the LULC maps was also checked against the photographs of the study area, as well as the GPS coordinates collected during the field survey between August 2011 and December 2011.

3.4.5 The change detection process

The post-classification change detection technique was applied to detect the extent of change in the Kat River Basin between 2001 and 2011. The images were cross-tabulated with each other to establish the spatial distribution of the LULC classes using the cross-tabulation module in Idrisi Taiga. The 2001 SPOT HRG image was cross-tabulated with the 2007 and 2011 images. The 2007 and 2011 images were also cross-tabulated. The result of the 2001-2011 analysis provides an indication of the overall LULC change that has taken place in the study area during the decade under spotlight. The 2001-2007 and 2007-2011 analysis on the other hand provides a comparison of the two halves of the decade to establish the half during which LULC change was more intensive.

3.5 Results of the analysis

Land Use/Land Cover maps for the years 2001, 2007, and 2011 are presented in Figures 3.1, 3.2, and 3.3 respectively. The results of the land use/land cover change detection analysis between 2001 and 2011 are presented in Tables 3.2 and 3.3, as well as Figure 3.4. Table 3.2 presents the overall classification process accuracy for the 2001; 2007; and 2011 satellite images. The section that follows presents the trends observed from the land use/land cover change analysis.

3.5.1 Classification of land use/land cover (LULC) from the images

3.5.1.A LULC classes

As observed in Table 3.2, the overall accuracy assessment for the 2001 image was 92 percent with the kappa coefficient of 0.91. For the 2007 image, an overall accuracy assessment was 90 percent, and the kappa coefficient was 0.88. The 2011 image analysis returned an overall accuracy assessment of 91 percent, with a kappa coefficient of 0.84.

Classification of land use/cover from the 2001, 2007, and 2011 satellite images yielded the land cover/use maps presented in Figures 3.2 A (land use in 2001); 3.2 B (land use in 2007); and 3.2 C (land use in 2011) and Table 3.3. These illustrations thus present the most prominent land use/cover classes in the Kat River Valley. These are: water bodies, forest land, citrus farms, built environment, rangeland, and bare surfaces. In 2011, water bodies accounted for 1.25 percent of the entire surface area in the Kat River Valley. Built Environment accounted for 5.45 percent of the entire surface area, whilst commercial citrus farming accounted for 16.43 percent. Bare surfaces, forest land, and rangeland accounted for 19.53 percent, 27.76 percent, and 29.58 percent respectively of the entire surface area of the study area. A comparison of the area occupied by these land use/cover practices in 2011 and 2007 and 2001 is presented in Figures 3.6 and 3.7 and Table 3.4.

Table 3.2: The accuracy assessment summary of the land use/ land cover (LULC) analysis for the years 2001, 2007, and 2011

Cat.	2001			2007			2011		
	Producer %	**User %**	**Kappa**	**Producer**	**User**	**Kappa**	**Producer**	**User**	**Kappa**
WB	80	90	0.79	81	84	0.81	82	83	0.80
F	86	78	0.96	96	93	0.92	87	88	0.90
C	82	84	0.93	95	99	0.79	90	92	0.94
BE	86	86	0.96	88	93	0.87	95	96	0.78
R	88	88	0.96	88	98	0.95	96	97	0.79
BS	91	98	0.94	79	90	0.98	88	98	0.83
OAA	92		0.91	90		0.88	91		0.84

Legend: Cat. = Category; WB = Water Bodies; F = Forest; C = Citrus; BE = Built Environment; R = Rangeland; BS = Bare Surfaces; OAA = Overall Accuracy Assessment

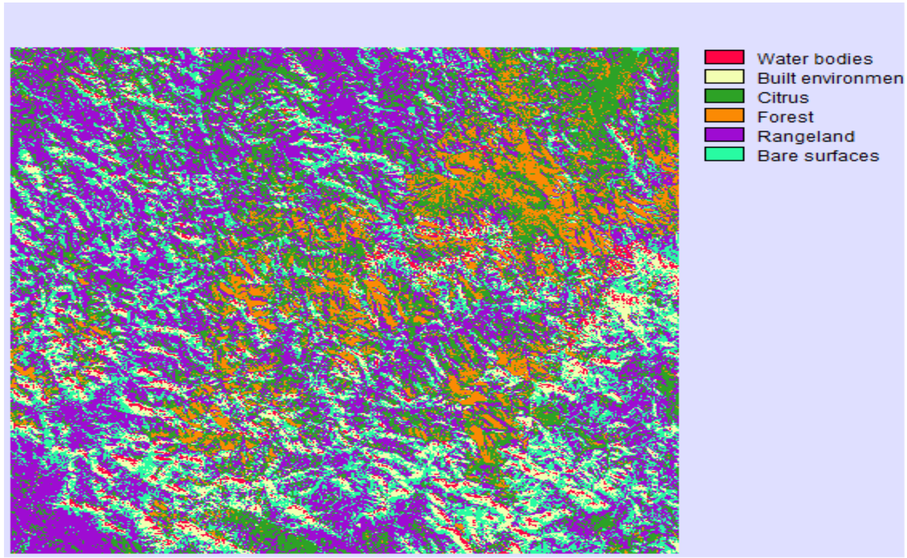

Figure 3.1 A: The 2001 LULC Map of the Kat River Valley

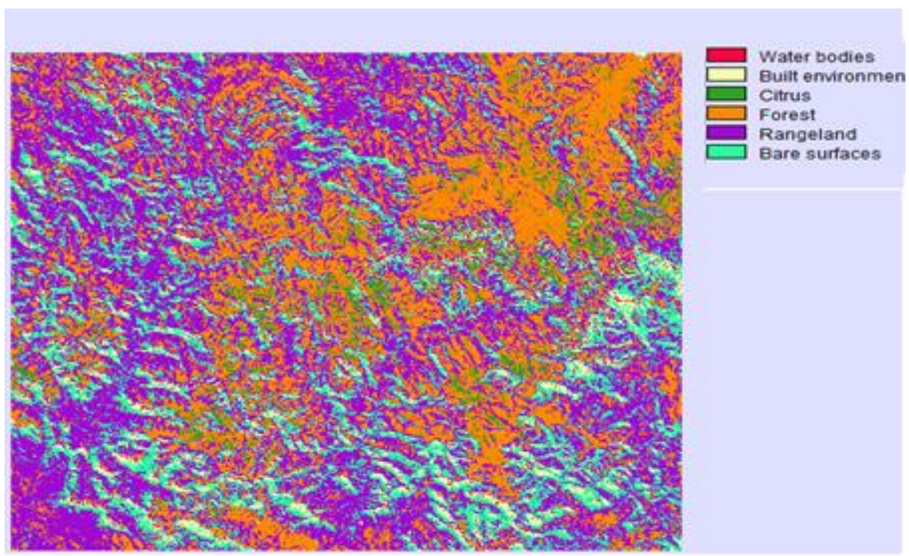

Figure 3.1 B: The 2007 LULC Map

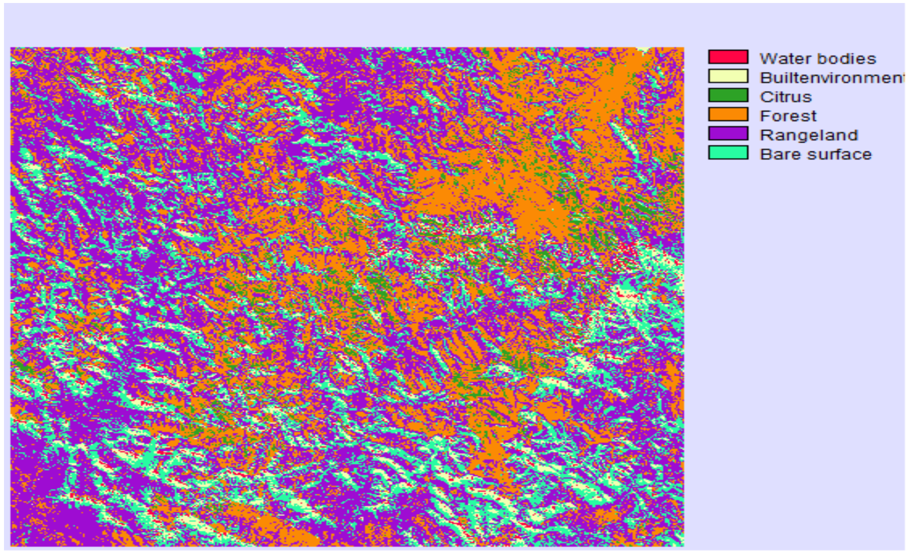

Figure 3.1 C: The 2011 LULC Map

3.5.1.B Land Use/Cover Change

In Table 3.3 and Figure 3.3, the following trends about the land use/cover change in the Kat River Valley in 2001, 2007, and 2011 are observed:

- In 2001, the most prominent land use in the study area (1348.51 km^2) was rangeland. Citrus farming occupied the second most prominent land use/cover practice in the study area, accounting for 822.87 km^2. Bare surfaces, and forest land accounted for 695.58 km^2 and 547.23 km^2 respectively. Water bodies and built environment accounted for 104.88 km^2 and 48 km^2 respectively.
- In 2007 though, bare surfaces became the most prominent land use/cover practice as the surface area they covered increased from 695.58 km^2 to 1242.77 km^2. They were followed by rangeland, whose size had decreased from 1348.51 km^2 to 920.64 km^2. In 2007, the land used for citrus farming had decreased from 822.87 km^2 to 494.27 km^2. Forest land area increased between 2001 and 2007 from 547.23 km^2 to 718.93 km^2.
- In 2011, rangeland had become the most prominent land use/cover activity again with a surface area of 1064 km^2. This however was still less than the total surface

area of this particular land use/cover class of 2001 by 283.72 km^2. Between 2007 and 2011, the area of bare surfaces classes became smaller from 1247.77 km^2 in 2007 to 702.90 km^2 in 2011. The land used for the commercial citrus farming increased by 97.29 km^2 from 494.27 km^2 in 2007 to 591.56 km^2 in 2011. The forest land area also increased between 2007 and 2011 from718.93 km^2 to 999.25 km^2.

Table 3.3: The quantification of the most prominent LULC practices

LULC Class	2001(km^2)	2007(km^2)	2011(km^2)
Water bodies	104.88	87.99	45.15
Forest	547.23	718.93	999.25
Citrus	822.87	494.27	591.56
Built Environment	80.93	135.40	196.35
Rangeland	1348.51	920.64	1064.79
Bare-surfaces	695.58	1242.77	702.90

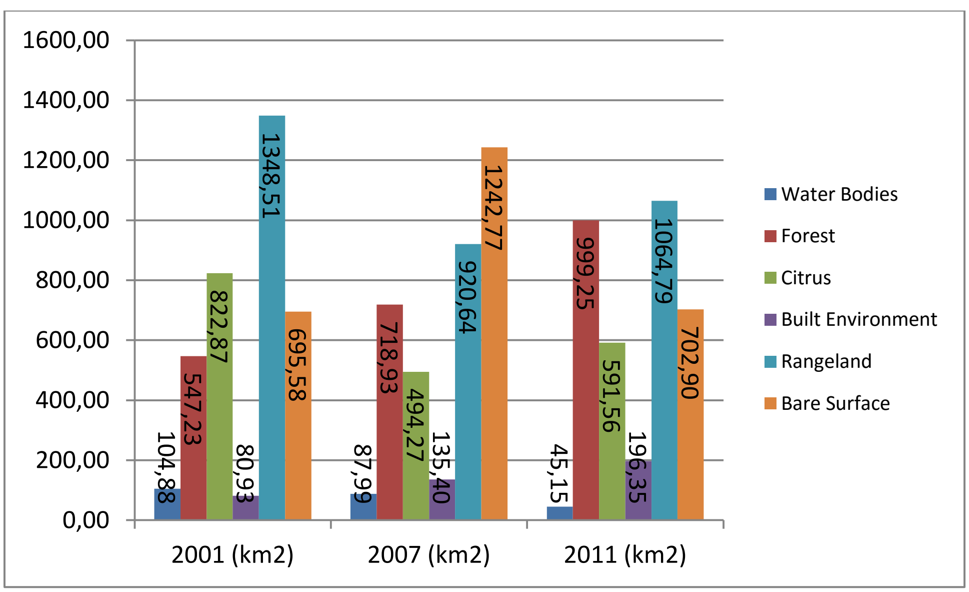

Figure 3.2: The quantification of the most prominent land use/cover practices (in km2) in the Kat River Basin in 2001, 2007, and 2011

Figure 3.3 presents the percentage cover of each land use class per date. Some land use/cover classes' areas increased whilst others decreased. For example, in 2001, forest covered 15.2 percent of the entire surface area of the Kat River Valley, while in 2011, this land use/cover class accounted for 27.8 percent of the entire area in the Kat River. Thus, between 2001 and 2011, this land use class increased by 12.6 percent. However, 7.8 percent of that increase however occurred between 2007 and 2011, compared to the 4.8 percent increase that took place between 2001 and 2007. Between 2001 and 2011, the area of Built Environment also increased by 3.3 percent, from 2.2 percent of the entire surface area to 5.5 percent. The area of bare surfaces also increased by 0.2 percent between 2001 and 2011. Between 2001 and 2007 though, the area of this land use/cover class increased by 15.2 percent and decreased by 15 percent between 2007 and 2011.

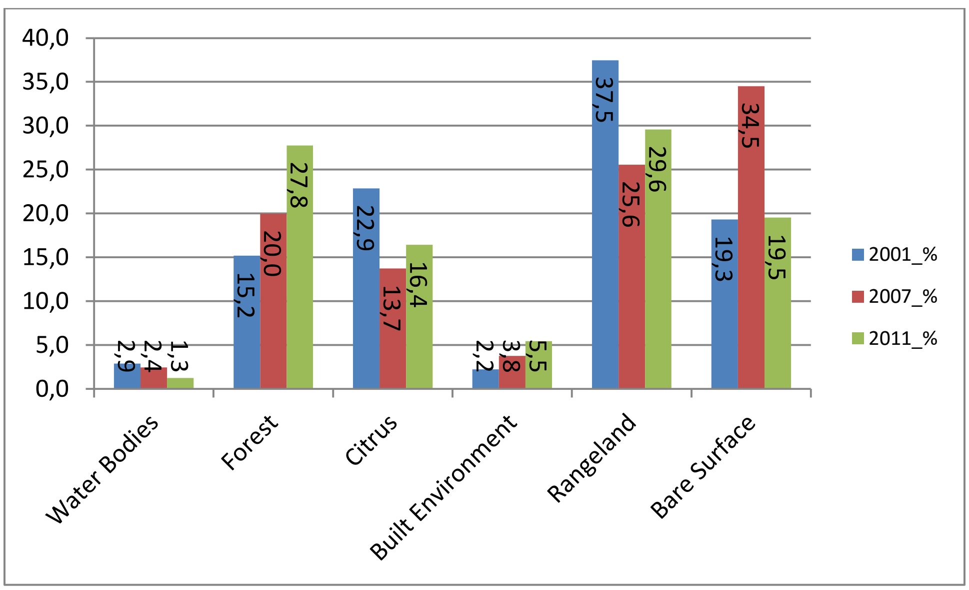

Figure 3.3: A comparison of the percentage of surface area covered by six land use/land cover classes in 2001, 2007, and 2011

On the other hand, the areas of commercial citrus farming and rangeland decreased between 2001 and 2011. Commercial citrus farming decreased by 6.5 percent between 2001 and 2011. The reduction of the area used for this land use/cover class was however sharper (9.2 percent) between 2001 and 2007. By comparison, the area of this land use/cover class increased by 2.7 percent between 2007 and 2011. A similar trend is observed in the rangeland area. Between 2001 and 2011, rangeland decreased by 7.9 percent. However, the reduction in the area of this land use/cover class was sharper between 2001 and 2007 (accounting for the 11.9 percent). A four percent increase in the area of this class was observed between 2007 and 2011.

3.6 Discussion

Table 3.4 illustrates the following trends regarding land-use practices in the Kat River Valley between 2001 and 2011:

3.6.1 The trends

3.6.1.A Forest

The forest area increased from 15.2 percent in 2001 and 27.8 in 2011, a 12.6 percent increase in the total area of this land-use. Between 2001 and 2007, this land-use increased by 4.8 percent from 15.2 percent to 20 percent. An even greater increase in the area of this land-use (7.8 percent) was observed during the 2007 – 2011 period.

3.6.1.B Built-Environment

The area covered by the built environment increased by a total of 3.3 percent between 2001 and 2011 from 2.2 percent in 2001 to 5.5 percent in 2011.

3.6.1.C Water Bodies

The area covered by water bodies was less by 1.7 percent in 2011, compared to 2001. It is also crucial to note that, only 29.3 percent of that reduction happened between 2001 and 2007. 64.7 percent of this reduction happened between 2007 and 2011. The seemingly dwindling area of water bodies in the area corresponds with increases in citrus farming land by 2.7 percent and built environment by 1.7 percent during the same period.

3.6.1.D Citrus Development

Table 3.4 indicates that the citrus land was 6.5 percent lesser in 2011 than 2001. In 2001, this land-use activity covered 22.9 percent of the land surface of the study area, compared to 16.4 percent in 2011. Crucial to note though is that, by 2007, the commercial citrus land had dwindled to 13.7 percent of the entire land-use, a reduction of the area of this land-use activity by 9.2 percent. This land-use activity occupied 2.7 percent more land in 2011, compared to 2007.

3.6.1.E Rangeland

A trend similar to that of the citrus development land-use practice was observed in the rangeland category also. The area covered by this land-use category was smaller by 7.9 percent in 2011 compared to 2001. In 2007, rangeland had dwindled by 11.9 percent. Thus, between 2007 and 2011, rangeland area increased by 4 percent.

3.6.1.F Bare Land

Table 3.4 shows that bare land area was 0.2 percent more in 2011 compared to 2001. Crucial to note however is that, the area of this land-use category increased by 15.2 percent from 19.3 percent to 34.5 percent in 2007. A 19.3 percent reduction from 34.5 percent to 19.5 percent was observed in 2011.

Table 3.4: The trends of land use change between 2001 and 2011

Class	2001_%	2007_%	2011_%	%diff (01-07)	%diff (07–11)	%diff (01-11)
W.	2.9	2.4	1.3	-0.5	-1.1	-1.7
F.	15.2	20	27.8	4.8	7.8	12.6
C	22.9	13.7	16.4	-9.2	2.7	-6.5
BE	2.2	3.8	5.5	1.6	1.7	3.3
R	37.5	25.6	29.6	-11.9	4	-7.9
BL	19.3	34.5	19.5	15.2	-15	0.2

3.6.2 Discussing the trends

As was reported in the previous section, a sharper change was observed on several land use/cover classes between 2001 to 2007 than between 2007 and 2011. The land use/cover classes manifesting this trend are commercial citrus farming, rangeland, and to a lesser extent, bare land. A possible explanation to this would be that, the period between 2001 and 2007 is longer than the period between 2007 and 2011, and thus, more change would be expected during the former period than the latter. However, this explanation would fail to account for a sharper change observed during the 'shorter' 2007 – 2011 period in water bodies, built environment and forest land use/cover classes.

The most likely explanation was derived from the 2001, 2007, and 2011 topographic maps (1:50, 000) of the study area. The 2007 and the 2011 maps show the following trends:

- Most of the land that was in 2001 intensively used for cropping vegetables and other crops in the upper catchment was now lying fallow. The decaying infrastructure and abandoned equipment would seem to indicate that the community agricultural cooperative HACOP that was in operation in 2001 has abandoned the cropping activities.

- Vegetation clearance in some of the old citrus farms that lay fallow in 2001 had happened by 2007 as the farms were being re-developed to be active in citrus production. In 2011, an even greater amount of land was developed in the upper middle, middle and lower middle reaches of the Kat River Valley. Vegetation was cleared. Citrus trees were being planted, irrigated, and agro-chemicals were being applied. These activities would explain the reduction in rangeland and a corresponding increase in bare land. Since it takes up to five years for citrus trees to grow in full, the newly developed citrus farms would continue being sensed as bare surfaces by the satellites. It would however be expected that as these trees grow bigger, the bare land class will get smaller. This is a possible explanation for the 2.7 percent increase in citrus land area between 2007 and 2011.

The pictorial evidence (Plate 3.7) collected during the field observations confirms the new citrus development in the Kat River Valley.

Plate 3.1: Land prepared for new citrus development in the Kat River basin

By implication, this activity included the conversion of what has since developed into a natural forest into citrus land. Emadi *et al*. (2009) examined how land use change affects the soil fertility properties within water-stable aggregates of the two cultivated soils in northern Iran. They thus compared the distribution of the nutrients and carbohydrates within such soils. They established that the mean weight diameter and water-stable aggregates were bigger in the forest and pasture lands than the neighboring cultivated lands. Emadi *et al*. (2009) also observed that, the virgin forest and grasslands were significantly richer in organic carbon, nitrogen, phosphorus, and carbohydrates than the exposed cultivated lands. Overall, Emadi *et al*. (2009) observed that, the conversion of the forest and grass lands into cultivation lands resulted in the significant reduction in the nutrient content of these soils. Verburg *et al*. (2004) identified the frontier deforestation as the primary cause of the forest degradation. They also highlighted the biodiversity implications of such a practice due to primarily, the loss of habitat (Verburg *et al*, 2004).

In an earlier attempt to establish the impact of change in land use practices on ecosystem integrity, Jepsen *et al*. (2005) conducted a study to establish how the five pre-selected species (*B. lampros*, a carabrid beetle*; O. fuscus*, a linyphiid spider*; A. arvensis*, a skylark*; M. agrestis*, a field vole*;* and *C. capreolus*, a roe deer) would behave under the two different simulated scenarios in Denmark. The first scenario, termed *GWAP*, involved a decrease in agricultural land, with a corresponding permanent increase in grassland and deciduous forest. The *GWAP* simulation indicated a positive impact on the carabid beetle and the two mammal species: field voe and roe deer. This positive effect was attributed to a direct benefit derived from an increase in high quality forage and improved habitat (Jepsen *et al*. 2005). On the other hand, the skylark and spider were negatively impacted, primarily due to reduction in the agricultural land use (Jepsen *et al*. 2005).

The other simulation conducted by Jepsen *et al*. (2005), termed *NOPE,* involved the phasing out of the use of pesticides in the production of cereal and oilseed rape. The results of this simulation showed increases in the populations of both the carabrid beetle and the linyphiid spider, inspite of the overall reduction in its primary reproductive habitat. The increase in both populations was attributed to the reduced mortality because of the phasing away of the pesticides (Jepsen *et al*. 2005).

Several hydrological factors and processes are particularly sensitive to land use change. Schiettecatte *et al*. (2008) observed that, just the mere introduction of a legumous crop in a crop rotation practice between tobacco and maize brought a reduction in crop management factor from 0.478 to 0.369. Increasing the number of crops (sweet potato, beans, maize, cassava, and fallow) that were inter-cropped during crop rotation resulted in a further reduction in the crop management to 0.245 (Schiettecatte *et al*. 2008). Camorani *et al*. (2005) observed that, the reclaimed land to land use changes in the Po River plain in northern Italy was significantly sensitive to floods. They also observed a negative correlation between the recurrence of a flood event and the sensitivity of the reclaimed land, in that, the sensitivity of the reclaimed land seemed to increase with the decrease in the recurrence interval of the storm event (Camorani *et al*. 2005). Berka *et al*. (2000) linked the poor groundwater and surface water quality in the Sumas River Basin in the Washington State and British Columbia to the intensification of agricultural practices in the area.

The dwindling water resources in the study area in light of, seemingly, a re-awakened interest in agricultural activities (livestock farming and cropping) as evidenced by the increases in rangeland and commercial faming between 2007 and 2011, is a reason of concern. This evidence and the pictorial evidence presented in Plate 3.8 seem to indicate a trend of agricultural intensification in the Kat River Basin between 2007 and 2011. Schiettecatte *et al*. (2008) established that, in the Cuyaguateje watershed in Cuba, the parcels of land used for agriculture had the highest erosion risk. Literature evidence exists that links water quality to the intensification of agricultural activities in a basin. For example, conducting a study in a basin similar to the Kat River (rural and the intensification of agricultural activities), Berka *et al.* (2001) linked the water quality challenges in that basin to the agricultural intensification activities. They observed higher nitrate and orthophosphate concentrations in the Sumas River in Canada after the intensification of agriculture in the basin. Houlahan and Findlay (2004) blamed the conversion of forested land to agriculture for the decline in the quality of stream and lake water quality. They also blamed the same change in land use/cover for the degradation of an adjacent wetland in Ontario, Canada. They also established that, the effect of land use on wetland and water quality can 'extend over comparatively large distances' (Houlahan and Findlay, 2004: 677).

Plate 3.2: The dwindling area of water resources in the Kat River Valley

Berka *et al*. (2001: 395) also observed that, groundwater in the Sumas River Basin was 'heavily contaminated with nitrates'. They blamed this on the overland agricultural intensification. The implication of increased nitrates on groundwater was the elevated levels of nitrate in the Sumas River during the low rainfall season when the main source of flow in the river is groundwater (Berka *et al*. 2001). Berka *et al*. (2001) also reported that the orthophosphate levels in the river were above the Canadian eutrophication prevention water quality guideline of 0.01 mg/l. They also pointed out that, the levels of coliforms in the Sumas River exceeded 200 MPN per 100 ml, thus rendering the river water unfit for recreation.

Berka *et al*. (2001) also blamed agricultural intensification for the significant dissolved oxygen and ammonia challenges in the Suma River. They observed that these two water quality variables deteriorated in the river water during the season of increased manure application. Projections made from the 1970 – 2000 water quality data seem to indicate that the quality of water in the Sumas River would continue to deteriorate with time (Burka *et al*. 2001). As was noted earlier, Haynes and Michalek-Wagner (2000) implicated intensive crop farming agriculture for the elevated diurons, dioxins, dieldrien, mercury, and cadmium concentrations in the Great Barrier Reef and Queensland coastlines.

The 2.5 times increase in the built environment between 2001 and 2011 in the Kat River Basin (Plate 3.9) may also have critical implications for both the water quality of the adjacent water bodies and their hydrological properties.

Plate 3.3: The newly constructed low-income township in Seymour, Kat River Valley

A 2007 study by Kulabako *et al*. attributed the increased water quality deterioration of the shallow groundwater in Kampala, Uganda during the wet season to the effects of the surface runoff transporting contaminants from the peri-urban settlements in the vicinity of the water table. In particular, Kulabako *et al*. (2007) observed elevated levels of nitrate, as well as the microbial contamination from the water samples collected from the shallow groundwater. The medians of both variables were reportedly in excess of the World Health Organisation's and Ugandan drinking water quality guidelines (Kulabako *et al*. 2007). The observations by Kulabako *et* al. (2007) were in line also with the findings reported earlier by Elmanama *et al*. (2006). The analysis of the water samples collected from the Lunzu Stream in Malawi returned the FC levels ranging from 0-500 (Pulamuleni *et al.* 2004) . Fatoki *et al*. (2001) also recorded elevated levels of FC in the Mthatha River, in South Africa.

All authors above linked the water quality challenges in their respective study areas to the land use and related practices in their respective basins. The deterioration in water quality during the wet season was attributed to the effect of surface runoff transporting elevated levels of contaminants into the shallow water table (Kulabako *et al*. 2007) from the riparian communities. In particular, Kulabako *et al*. (2007) blamed 'scattered waste disposal' in the area for the elevated levels of contaminants transported by runoff into the shallow water table. Fatoki *et al*. (2001) blamed informal settlements with no proper sanitation for the microbial water quality challenges in the Mthatha River. Palamuleni *et al*. (2004) and Elmanama *et al*. (2006) identified runoff from the adjacent settlements and related land-use practices as the primary contributor to the water quality deteriorations in their respective study areas. Also, Masamba and Mazvimavi (2008) hinted on the possibility of the pollution in the form of organic matter and nitrogen from the built environment (residential areas; lodges; hotels) as well as grazing by cattle and donkeys in the Thamakalane-Boteti River in the Okavango Delta, in Botswana.

3.7 Conclusion

In this chapter, evidence of land-use/land cover change that has occurred in the Kat River Valley is presented. Massive vegetation clearance happened in the study area between 2007 and 2011. Of major concern though is the effect brought about to the natural systems by such a change in land use. This is in view of the abundance of literature evidence presented above proving that, various land use practices impact the environment differently, and also that, the natural environment behaves differently from the impacts of varying land uses.

CHAPTER IV

AN INVESTIGATION AND ANALYSIS OF THE IMPACT OF THE WATER MANAGEMENT INSTITUTIONAL CHANGE ON THE WATER QUALITY OF THE KAT RIVER, EASTERN CAPE PROVINCE, SOUTH AFRICA

4.1 Overview

In 2001, the water management responsibilities in the Kat River were transferred from the Kat River Irrigation Board that was almost solely driven by the predominantly White citrus commercial farmers to the all-encompassing stakeholder-based Kat River Valley Water Users Association (KRVWUA). The impact this institutional change may have on the Kat River water quality is not yet quantified, and is unknown. In this study, the impact of the KRVWUA on the salinity and nutrient statuses of the Kat River in the first decade of its establishment (2001 – 2010) is investigated. The paired sample t-test was conducted to establish if the salinity and nutrient statuses of the Kat River was significantly different between the periods 1991 – 2000 and 2001 – 2010 at $\alpha = 0.05$. Significant increases in chloride, calcium, potassium, ammonium, and nitrate were observed at the Kat Dam site. At the Balfour River site, significant decreases in the levels of chloride, electrical conductivity, sodium, sulphate, and pH, as well as calcium were observed. No significant difference was observed between the two decades in the Fort Beaufort site. In order to improve the quality of water in the upper Kat River catchment, it is recommended that: runoff controls are developed: - efforts are required to keep animals off the rivers; environmentally friendly toilet systems are required in the study area; graveyards to be closed, and a suitable site be established away from the stream course, the environmentally friendlier conservancy systems to replace the septic tanks, and be located away from the river basin.

4.2 Introduction and problem statement

In the last three and a half centuries, the legal philosophy of the ruling class in South Africa has changed four times, and every time it was changed, a different set of water rights has emerged. Pienaar and van der Schyff (2009) identified two pre-1998 distinct phases within which water rights evolved in South Africa (the common-law practice – in which the government holds the right to control water in a stream; and riparian ownership – riparian owners have a right to a share of water flowing through or alongside their property). Tewari (2009) however identified the four broad periods as follows. The first is the pre-colonial period under African customary law (before 1652). During this period, land and water rights were communally held, but invested in, and controlled by the traditional chief. The second is the Dutch East India Company (DEIC) here after rule spanning from 1652 to around 1810. The DEIC adopted the Roman/Dutch law advantaging the riparian land owners, but water and land rights were still controlled by the state. The third is the British Colonial law, followed by the rule of the Afrikaner apartheid law (around 1810 – 1990). During this period, water rights were governed using the English law that significantly lessened the control of the state over the resource, effectively putting control of the resource in the hands of the economic elite in the industrial, mining, and agricultural sectors. The fourth is the democratic modern law (1991 – present). During this era, the state has been recognized as the custodian of both land and water resources (Tewari, 2009).

As indicated by Tewari (2009), the new democratic dispensation in South Africa seems to have sustained the trend of linking the change in the water resource management philosophy to the change in the legal philosophy of the ruling class. This is evidenced in the country's primary water management legislation, the South African National Water Act No. 36 of 1998 (NWA, 1998). In NWA (1998), the transformation is mandated of the local water management institutions from the primarily White Irrigation Boards to the more inclusive Water Users Associations (WUA). This was particularly necessary where more than one population race group share an interest in a particular river basin.

The Kat River Basin, being shared among the White South Africans, Black South Africans (predominantly AmaXhosa), and South African Coloured communities is, typically, such a basin.

In view of the racial diversity of the Kat River Basin community, in 2000/1, the water management responsibilities in the Kat River were transferred from the Kat River Irrigation Board, which was almost solely driven by the White citrus commercial farmers to the then newly-formed all-encompassing community-based Kat River Valley Water Users Association (KRVWUA) here after. The impact this institutional change may have on the quality of the Kat River water is not yet quantified, and is therefore unknown. What is required is the quantification of the impact of the institutional change in the Kat River water management on the Kat River water quality. This study, therefore, investigates the impact of the Kat River Valley Water User Association on the salinity and nutrient status of the Kat River in the first decade since its establishment (2001 – 2010). Following are the objectives of the study, and their related research questions:

- examining the impact of institutional change on the salinity and nutrient status of the Kat River water;
    - Is there a statistically significant difference in the nutrient status of the Kat River water before and after the establishment of the KRVWUA?

Following are the study's objectives:

- Establishing if the nutrient status of the Kat River is statistically significantly different in the periods between 1991 – 2000 and 2001 – 2010.
    - Is there a statistically significant difference in the nutrient status of the Kat River water in a decade before (1991 – 2000) and a decade after 2001 – 2010) the establishment of the KRVWUA?

  Null: There is no significant difference between the means of the two decades.
  Alternate: There is a significant difference between the means of the two decades.

- Establishing if the salinity status of the Kat River water is statistically significantly different in the period between 1991 – 2000 and 2001 – 2010
    - Is there a statistically significant difference in the salinity status of the Kat River water in the decade before (1991 – 2000) and the decade after (2001 – 2010) the establishment of the KRVWUA?

4.3 Description of the study area

4.3.1 Biophysical characteristics of the study area

The climate of the study area is mild (Motteux, 2000). Summer temperatures vary between 20^0C and 35^0C . Winter temperatures vary between 0^0C and 20^0C (Schoombe *et al*. 1997). Annual average rainfall of the study area is 400mm in the immediate vicinity of Fort Beaufort and 1200mm in the upper Kat River area (Schoombe *et al*. 1997). The area receives most of its rainfall in the October/November and February/March periods (Schoombe *et al*. 1997). Rainfall received in the study area varies between low intensity-long duration and high intensity- short duration types (Schoombe *et al*. 1997). The area is also characterised by great variability of rainfall (Barrett et al. 2001).

The altitude in the area ranges between 1600 metres at the source of the Kat River, which is the top of the escarpment, and 600 metres at the confluence with the Fish River (Haughton, 1964). The river valleys are deeply incised and characterised by narrow alluvial terraces bordering the river (Barrett et al. 2001). The vegetation is largely of the valley bushveld and river thicket type, although, at high altitudes, pockets of Afro-montane forest and grassland vegetation are evident (Motteux, 2000).

The study area's geology forms part of the Beaufort series of the Karoo system (Geological Map of Southern Africa). It belongs to the Molteno, Red Bed and Cave Sandstone Stages (Geological Map of Southern Africa). Dominant rocks include shale, mudstone, sandstone, and limestone (Geological Map of Southern Africa). According to

Barratt (1998), geology affects the quality of water resources in a number of ways. These include the rate at which the river erodes and transports materials along its course. In turn, erosion determines the amount of sediment available for transportation by the river, and hence its turbidity (Barrett et al. 2001). Barratt (1998) further points out that the type of rock structure over which the river flows may be one of the major sources of salts and metals in many river systems.

4.3.2 Historical background to the study area

Most of the area, especially in the upper and middle sections of the basin, belonged to the former Ciskei homeland government (Motteux, 2000). According to the Water Research Commission (WRC, 1997), this area falls into the Tsitsikama and Fish River Water Management Area. The Kat River falls within the primary catchment area of the Great Fish River (WRC, 1997).

The farmlands in the area were used by White and Coloured farmers, with tobacco, potatoes and citrus fruit being the main agricultural commodities till the 1970s (Nel and Motteux, 1999; Motteux, 2000). The reliable flow of the Kat River, regulated by a dam since the 1970s, and fertile valley soils encouraged the practice of successful intensive irrigation farming (Motteux, 1999). The transference of the land to the Ciskei homeland government in the late 1970s to the early 1980s led to the migration of White and Coloured communities out of the area (Nel and Hill, 1996). The migration of the White and Coloured commercial farmers adversely affected the African populations economically (Motteux, 1999). They lost their jobs, and the apartheid policies also had denied them access to any means of production in the area (Nel and Hill, 1996).

The para-statal (partly owned by the state), Ulimcor, took up some of the ex-white farms to provide farming assistance to support interested farmers in the Kat River (Nel and Hill, 1996; Nel and Motteux, 1999). These farms were transferred to Black emerging farmers to manage. These farm managers were however only granted rights to use the land, and were never granted the ownership of the land. As a result, these farm managers became reluctant to invest on the land they did not own (Nel and Motteux, 1999). Consequently, until recently, most of these farm lands lay fallow, with no land tenure. The exception in this instance is the Fairbairn area, in which some of the land has been privately owned since the early 1900s (Nel and Hill, 1996). Part of the most productive land in the area (lower-middle reaches immediately upstream of Fort Beaufort and the lower reaches downstream of Fort Beaufort) was never transferred to the former Ciskei homeland, and has been under the predominantly white commercial citrus farmers for generations (Mottex, 1999).

4.4 Methodology

4.4.1 The study sites

Three sites in the Kat River Basin were identified for the water quality comparison of the pre-2000 and post-2000 decades as follows: two of the sites are located on the main Kat River (102494 – the Kat River Dam and 102496 – just upstream of the Fort Beaufort town), while the other (102488) is located on one of the largest tributaries of the Kat River (Balfour River) between the two Kat River sites.

4.4.2 The water quality variables of concern and their determination from the samples

While several water quality variables were monitored during that period in the study area, nine (9) variables were selected for the current study, and these are: chloride (Cl), electrical conductivity (EC), sodium (Na), sulphate (SO_4), and pH were used to determine the change in salinity status of the Kat River since the establishment of the KRVCF and KRVWUA, while calcium (Ca), potassium (K), ammonium (NH_4), and nitrate (NO_3) were used to determine the change in the river's nutrient status in the same period. The Ion Chromatographic methodology was adopted for the determination of chloride. The Inductively Coupled Plasma Atomic Emission

Spectrometry was used for the determination of Na, Ca, and K. For EC and pH determination, the Resource Quality Services (RQS) Automated Measurement EC and pH Radiometer, was used. The RQS Automated Filter Membrane NO_3+ NO_2 photometric determination 540 NM AQUAKEM 250 was used for the determination of NO_3. NH_4 was determined using the RQS Automated Filter Membrane NH_4 Photometric Determination 660 NM. The AQUAKEM 250 was used for the determination of ammonium. Sodium determination was conducted using the RQS Automated Filter Membrane Na Atomic Absorption Spectrometer Air/Acetylene – SPECTRAA 220 FS.

4.4.3 Data sources

The water quality data for the two sites on the main Kat River was obtained from two sources, Resource Quality Services (RQS), a national government agency in South Africa, and the Amathole District Municipality (ADM). In a few instances, the water quality data of the Kat River Citrus Cooperative, Ltd (KATCO) was used to supplement both the RQS and the ADM data sets. This was necessitated by the fact that, RQS stopped monitoring of the sites in 2004, handing over the monitoring responsibilities to the local government, the Amathole District Municipality (ADM). For that reason, for both sites on the main Kat River, the RQS provided data only for the 1991 – 2004 period. The RQS however provided data up to 2010 for the Balfour River site.

4.4.4 Data pre-processing

The RQS frequency of sampling was monthly, while it was quarterly for the ADM. The data thus had to be normalized to a quarterly frequency for a good comparison using Tobler’s Law of Geography. This was achieved by identifying the dates that were as close as possible to the quarterly observations on the monthly data, and retaining them, while the rest of the data were discarded. The end result was the data for each data set that indicate 4 observations in a year, with dates of observation as close to each other as possible.

The datasets for the Balfour River's sites were also converted to monthly observations. This was achieved by computing a mean of the month for the months that had more than one observation of a particular water quality variable. This was necessitated by the fact that, from the original dataset, some months had one observation while others had up to four observations for a particular dataset.

4.4.5 Data analysis

The paired samples t-test was used to compare the means of the 1991 – 2000 dataset to the 2001 – 2010 means on all three sites for each of the pre-selected water quality variables to establish whether water quality had improved or depreciated over the last 10 years of the KRVWUA existence. This paired samples t-test was used to test the following hypothesis:

H_{a1}: There is no significant difference between the means of the pre-2000 and the post-2000 means of the nutrients (calcium, potassium, ammonium, and nitrate) at the three sites in the Kat River Basin.

H_{o1}: There is a significant difference between the means of the pre-2000 and the post-2000 means of the nutrients (calcium, potassium, ammonium, and nitrate) at the three sites in the Kat River Basin.

H_{a2}: There is no significant difference between the means of the pre-2000 and the post-2000 means of the salinity (chloride, electrical conductivity, sodium, sulphate, pH) at the three sites in the Kat River Basin.

H_{o2}: There is a significant difference between the means of the pre-2000 and the post-2000 means of the salinity (chloride, electrical conductivity, sodium, sulphate, pH) at the three sites in the Kat River Basin.

The section that follows presents the results of the water quality data analysis.

4.5 Results and discussion

4.5.1 The Kat Dam site

4.5.1A Nutrients

Table 4.1 presents the descriptive statistics of the nutrients in the Kat Dam Site. The means of all variables are higher in the 2001 – 2010 than the 1991 – 2000 decade. The mean concentration for potassium rose by four percent in the 2001 – 2010 decade compared to the previous one. Also, nitrate and ammonium mean concentrations increased by 43.14 percent and by 44.34 percent respectively, while the calcium mean concentration was more than three times higher. Evidently, the Kat River at this point was nutrient more enriched during the 2001 – 2010 decade than the 1991 – 2000 decade. A negative correlation between the 1991 – 2000 and 2001 – 2010 means of all four variables compared was observed.

Table 4.1: Paired samples statistics of the nutrients at the Kat Dam site

	Variables	Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Ca 1991 - 2000 (mg/l)	6.6154	39	3.5140	.5627
	Ca 2001 - 2010 (mg/l)	20.7008	39	31.2285	5.0006
Pair 2	K 1991 - 2000 (mg/l)	2.1060	39	.5203	.0833
	K 2001 - 2010 (mg/l)	2.2112	39	.6155	.0986
Pair 3	NH_4 1991 - 2000 (mg/l)	.0538	38	.0304	.0049
	NH_4 2001 - 2010 (mg/l)	.0934	38	.1108	.0180
Pair 4	NO_3 1991 - 2000 (mg/l)	.2314	39	.1369	.0219
	NO_3 2001 - 2010 (mg/l)	.4090	39	.3321	.0532

The results of a test of whether the observed increases in concentrations of the four nutrients (Ca, K, NH_4, and NO_3) in the Kat Dam site are statistically significant are presented in Table 4.2. Table 4.2 shows that the means of calcium, ammonium, and nitrate concentrations of the 2001 – 2010 decade were statistically, significantly different when compared to those of the 1991 – 2000 decade. However, for the potassium, no significant difference was observed between the means of the 1991 – 2000 and 2001 – 2010 decades. Therefore, for calcium, nitrate, and ammonium, the null hypothesis is rejected, and the alternative hypothesis accepted at 95 percent confidence level. For the potassium however, because the difference between the means of the two decades is not statistically significant, the null hypothesis cannot be rejected.

4.5.1.B Salinity

Table 4.3 presents the descriptive statistics of the 5 variables (chloride, electrical conductivity, sodium, sulphate, and pH) used for salinity analysis in the Kat Dam site for the comparison of the means of the 1991 – 2000 and 2001 – 2010 decades. The 2001 – 2010 mean for chloride was 63.3 percent higher than the 1991 – 2000 decade. Sodium was about 14 percent higher during the same period. The means for the electrical conductivity, sulphate, and pH were all slightly lower for the 2001 – 2010 decade compared to the 1991 – 2000 decade. Table 4.4 presents some evidence of whether these differences are statistically different at 95 percent confidence level. Table 4.4 indicates that the only difference that is statistically significant in means between the 1991 – 2000 and 2001 – 2010 is that of chloride.

Therefore, for chloride, the null hypotheses that there is no significant difference in chloride concentration means between the 1991 – 2000 and 2001 - 2010 decades is rejected. On the other hand, for the electrical conductivity, sodium, sulphate, and pH the mean concentrations were not significantly different between the two decades.

Table 4.2: Paired samples test of significance of the difference of the Calcium (Ca), Potassium (K), Ammonium (NH_4), and Nitrate (NO_3) at the Kat Dam site

		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper	t	Df	Sig. (2-tailed)
Pair 1	Ca 1991-2000 – Ca 2001-2010	-14.085	32.2223	5.1597	24.5307	-3.6402	-2.730	38	.010
Pair 2	K 1991-2000 - K 2001-2010	-.1052	.8846	.1417	-.3920	.1816	-.743	38	.462
Pair 3	NH_4 1991-2000 – NH_4 2001-2010	-.0395	.1203	.0195	-.0791	.0001	-2.026	37	.050
Pair 4	NO_3 1991-2000 – NO 2001- 2010	-.1776	.3797	.0608	-.3006	-.0545	-2.920	38	.006

Table 4.3: Paired samples statistics of the salinity variables at the Kat Dam site

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Cl 1991 - 2000 (mg/l)	10.4975	40	1.9099	.3020
	Cl 2001 - 2010 (mg/l)	17.1430	40	9.9665	1.5758
Pair 2	EC 1991 - 2000 (µS/l)	16.9955	40	6.5212	1.0311
	EC 2001 - 2010 (µS/l)	16.0297	40	2.8860	.4563
Pair 3	Na 1991 - 2000 (mg/l)	12.4869	37	10.6675	1.7537
	Na 2001 - 2010 (mg/l)	14.211	37	3.5547	.5844
Pair 4	SO_4 1991 - 2000 (mg/l)	13.2078	39	6.6671	1.0676
	SO_4 2001 - 2010 (mg/l)	12.45176	39	5.1947	.8318
Pair 5	pH 1991 – 2000	7.92715	39	.1866	.0299
	pH 2001 – 2010	7.89363	39	.4194	.0672

Table 4.4: Paired samples test of significance of the difference of the Chloride (Cl), Electrical Conductivity (EC), Sodium (Na), and Sulphate (SO_4), and pH at the Kat Dam site

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	Df	Sig. (2-tailed)
Pair 1	Cl 1991-2000 (mg/l) - Cl 2001-2010 (mg/l)	-6.6455	10.8570	1.7167	-10.1177	-3.1733	-3.871	39	.000
Pair 2	EC 1991-2000 (µS/l) - EC 2001-2010 (µS/l)	.9658	7.0739	1.1185	-1.2965	3.2281	.863	39	.393
Pair 3	Na 1991-2000 (mg/l) - Na 2001-2010 (mg/l)	-1.7242	11.1991	1.8411	-5.4581	2.0098	-.936	36	.355
Pair 4	SO_4 1991-2000 (mg/l) – SO_4 2001-2010 (mg/l)	.7560	8.1743	1.3089	-1.8938	3.4059	.578	38	.567
Pair 5	pH 1991-2000 - pH 2001-2010	.0335	.4316	.0691	-.1064	.1734	.485	38	.630

4.5.2 The Balfour River site

4.5.2.A Nutrients

The descriptive statistic for the Balfour River site is presented in Table 4.5. The mean concentrations of calcium and potassium were less in the 2001 – 2010 decade than the 1991 – 2000 period. Calcium concentrations decreased by about 21 percent, while the potassium levels dropped by about 15 times. A slight increase was observed in ammonium and nitrate during the 2001 – 2010 decade from the preceding decade.

Table 4.5: Paired samples statistics of nutrients at the Balfour River site

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Ca 1991 – 2000	14.2004	39	6.4539	1.0334
	Ca 2001 – 2010	11.2450	39	3.6743	.5884
Pair 2	K 1991 – 2000	20.0545	107	190.7757	18.4430
	K 2001 – 2010	1.3471	107	.4125	.0399
Pair 3	NH_4 1991 – 2000	.0338	111	.0408	.0039
	NH_4 2001 – 2010	.0353	111	.0230	.0022
Pair 4	NO_3 1991 – 2000	.2006	39	.2035	.0326
	NO_3 2001 – 2010	.2384	39	.14678	.0235

Table 4.6 presents the results of the test of whether the differences between the 1991 – 2000 and 2001 – 2010 mean concentrations of nutrients in the Balfour River are significantly different statistically. Calcium concentrations are significantly different between the two decades at 95 percent confidence level. The null hypothesis is thus rejected, and the alternative, accepted. For potassium, ammonium, nitrate, there is

insufficient evidence that the means of the two decades significantly differ statistically. The null hypotheses cannot therefore be rejected.

4.5.2.B Salinity

The descriptive statistics of the Balfour River site for chloride, electrical conductivity, sodium, sulphate, and pH for both the 1991 – 2000 and 2001 – 2010 decades are presented in Table 4.7. It is observed from Table 4.7 that, the levels of all water quality variables got lower in the 2001 – 2010 decade compared to the decade preceding it.

The biggest reductions were: chloride – 2.4 times; sulphate – 38.04 percent; sodium – 36.62 percent; and the electrical conductivity- 24 percent. A test of whether these differences are statistically significant is presented in Table 4.8. As portrayed in table 4.8, for chloride, there is no significant difference between the 1991 – 2000 and 2001 – 2011. Thus, no conclusive evidence that the concentration means of chloride were different between the two decades.

However, the means of electrical conductivity, sodium sulphate, and pH differed significantly between the 1991 – 2000 and 2001 – 2010. The null hypotheses are thus rejected for the electrical conductivity, sodium, sulphate and pH.

Table 4.6: Paired samples test of significance of the difference of the Ca, K, NH_4, and NO_3 at the Balfour River Site

		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	Ca 1991-2000 – Ca 200-2010	2.9554	6.5319	1.0459	.8380	5.07281	2.826	38	.007
Pair 2	K 1991-2000 - K 2001-2010	18.704	190.7809	18.4435	-17.8586	55.2734	1.014	106	.313
Pair 3	NH_4 1991-2000 – NH_4 2001-2010	-.0015	.0454	.0043	-.0101	.0070	-.352	110	.725
Pair 4	NO_3 1991-2000 – NO 2001–2010	-.0378	.2497	.0400	-.1187	.0432	-.944	38	.351

Table 4.7: Paired samples statistics of the salinity variables at the Balfour River site

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Cl 1991 – 2000	32.6511	107	173.0108	16.7256
	Cl 2001 – 2010	13.6969	107	5.3648	.5186
Pair 2	EC 1991 - 2000	22.3053	110	11.1629	1.0643
	EC 2001 – 2010	16.9504	110	5.1804	.4939
Pair 3	Na 1991 - 2000	16.8638	107	11.2563	1.0882
	Na 2001 - 2010	10.6879	107	3.6503	.3529
Pair 4	SO_4 1991 - 2000	8.21149	110	4.8943	.4667
	SO_4 2001 - 2010	5.0878	110	2.7865	.2657
Pair 5	pH 1991 - 2000	7.9600	109	.3051	.0292
	pH 2001 - 2010	7.7632	109	.2437	.0233

Table 4.8: Paired samples test of significance of the difference of the Cl, EC, Na, SO_4, and pH at the Balfour River

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Cl 1991-2000 - Cl 2001 – 2010	18.9542	171.8767	16.6160	-13.987	51.8970	1.141	106	.257
Pair 2	EC 1991-2000 - EC 2001-2010	5.3549	10.9804	1.0470	3.2799	7.4299	5.115	109	.000
Pair 3	Na 1991-2000 - Na 2001-2010	6.1759	10.9610	1.0596	4.0750	8.2767	5.828	106	.000
Pair 4	SO_4 1991-2000 - SO_4 2001-2010	3.1237	5.8173	.5547	2.0243	4.2230	5.632	109	.000
Pair 5	pH 1991-2000 - pH 2001-2010	.1968	.3580	.0343	.1289	.2648	5.740	108	.000

4.5.3 *The Fort Beaufort site*

4.5.3.A Nutrients

Table 4.9 presents a comparison of the means of calcium, potassium, ammonium, and nitrate between the 1991 – 2000 and 2001 – 2010 at the Fort Beaufort site. The means of all four water nutrients were lower during the 2001 – 2010 period than the previous decade. Table 4.10 presents some evidence of whether the change of means between the two decades for each variable is significant statistically. It is observed from Table 4.10 that the difference in means of calcium, potassium, ammonium, and nitrate of the 2001-2010 period were not significantly different statistically. The null hypothesis therefore cannot be rejected.

Table 4.9: Paired samples statistics of nutrients at the Fort Beaufort site

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Ca 1991	26.3132	38	9.5636	1.5514
	Ca 1991	24.9476	38	10.8325	1.7573
Pair 2	K 1991	7.0511	38	26.8322	4.3528
	K 1991	2.1053	38	.4548	.0738
Pair 3	NH_4 1991	.5357	39	1.6015	.2564
	NH_4 1991	.3683	39	1.2555	.2010
Pair 4	NO_3 1991	2.9103	40	13.9679	2.2085
	NO_3 1991	.6590	40	.3802	.0601

Table 4.10: Paired samples test of significance of the difference of Ca, K, NH_4, and NO_3 at the Fort Beaufort site

		Paired Differences							
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Pair 1	Ca 1991-2000 – Ca 200-2010	1.3655	13.9189	2.2580	-3.2095	5.9406	.605	37	.549
Pair 2	K 1991-2000 - K 2001-2010	4.9458	26.8669	4.3584	-3.8851	13.776	1.135	37	.264
Pair 3	NH_4 1991-2000 – NH_4 2001-2010	.16744	2.0928	.3351	-.5110	.8458	.500	38	.620
Pair 4	NO_3 1991-2000 – NO 2001–2010	2.251	13.8090	2.1834	-2.1651	6.6676	1.031	39	.309

4.5.3.B Salinity

A comparison of the means of pH, chloride, electrical conductivity, sodium, and sulphate are presented in Table 4.11. The means of pH, electrical conductivity, and chloride levels were higher in the 2001 – 2010 period compared to the 1991 – 2000.

Table 4.11: Paired samples statistics of salinity indicators at the Fort Beaufort site

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	pH 1991 – 2000	7.9488	40	.4234	.0670
	pH 2002-2011	7.9558	40	.2948	.0466
Pair 2	Cl 1991 – 2000	56.2483	38	33.2833	5.3993
	Cl 2001 – 2010	64.8250	38	42.6934	6.9258
Pair 3	EC 1991 – 2000	45.9054	40	19.5010	3.0834
	EC 2001 – 2010	49.5268	40	24.5545	3.8824
Pair 4	Na 1991 – 2000	51.8748	40	27.1191	4.2879
	Na 2001 – 2010	48.2612	40	28.5200	4.5094
Pair 5	SO_4 1991 – 2000	20.6425	40	8.0561	1.2738
	SO_4 2001 – 2010	18.6633	40	8.7972	1.3910

For sodium and sulphate however, the means were lower during the 2001 – 2010 decade than the previous one. The results of the test of whether these differences are statistically significant are presented in Table 4.12. None of the differences in levels between 1991 – 2000 and 2001 – 2010 were statistically significant. The null hypotheses can therefore not be rejected.

Table 4.12: Paired samples test of significance of the difference of the Cl, EC, Na, SO_4, and pH at the Fort Beaufort Site

		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	T	df	Sig. (2-tailed)
Pair 1	pH 1991-2000 - pH 2002-2011	-.0070	.5437	.08598	-.1809	.1669	-.081	39	.936
Pair 2	Cl 1991-2000 - Cl 2001–2010	-8.576	47.6525	7.7303	-24.2397	7.0863	-1.109	37	.274
Pair 3	EC 1991-2000 - EC 2001-2010	-3.621	27.7970	4.3951	-12.5113	5.2686	-.824	39	.415
Pair 4	Na 1991-2000 - Na 2001–2010	3.6136	37.4878	5.9273	-8.3756	15.6028	.610	39	.546
Pair 5	SO_4 1991-2000 – SO_4 2001–2010	1.9793	11.6494	1.8419	-1.7464	5.7049	1.075	39	.289

4.6 Discussion

4.6.1 Introduction

As reported in the results section, a statistically significant difference between the means of the 1991-2000 and the 2001 – 2010 decades for some of the pre-selected variables was observed. This section seeks to explain the observed trends. The differences in the water quality variables and their explanations are presented below. Documented literature is used to link the water quality trends observed in the study area to land use and related activities.

4.6.2 Explaining the trends

4.6.2.A The Kat River Dam site in the upper reaches

The observed statistically significant increase in the mean concentrations of calcium, ammonium, and nitrate in the Kat Dam Site is an indication of the nutrient enrichment of the Kat River in the upper reaches. It is an indication of increased input of nutrients into the river system. The increase in chloride is a further indication that the water quality in the upper reaches of the Kat River is getting degraded.

Literature documents several factors leading to the increase in nutrient concentrations of a water body. For example:

- Clearance of native vegetation (Turner and Rabalais, 2003);
- Domestic waste water (Ma *et al*. 2009; Shrestha and Kazama, 2006);
- Non-point sources – agriculture and orchards (Shrestha and Kazama, 2006);
- Major reduction in the inflow water; (Ma *et al*. 2009);
- Nitrification process (Li *et al*. 2010) ;
- Urban sewage effluent (Li *et al*. 2010);
- Intensive and widespread farming (Turner and Rabalais, 2003; Spalding and Exner, 1993);
- Fertilizer use (Turner and Rabalais, 2003);
- Irrigation supported agriculture (Deutsch *et al*. 2006; Spalding and Exner, 1993);

- Wastewater Treatment Plants (Shrestha and Kazama, 2006);
- Industrial activity (Shrestha and Kazama, 2006);
- Row cropping (Smith *et al*., 2013; Randall and Muller, 2001);
- Extensive distribution of agricultural fields (Lee *et al*. 2008);
- Residential areas (Lee *et al*. 2008);
- Livestock farming (Lee *et al*. 2008);
- Groundwater (Deutsch *et al*. 2006; Goolsby *et al*. 1999; Spalding and Exner, 1993);
- Soil's nitrification processes (Bernhard *et al*. 2002; Goolsby *et al*. 1999);
- Atmospheric deposition (Deutsch *et al*. 2006; Bernhard *et al*. 2002; Whitehead *et al*. 1998), especially in predominantly forested watersheds (Bernhard *et al*. 2002);
- Agricultural (Bernhard *et al*. 2002; Goolsby *et al*. 1999); and
- Urban land use (Bernhard *et al*. 2002; Whitehead *et al*. 1998);
- Terrestrial environment (agriculture, and leakage from forest systems) (Whitehead *et al*. 1998) ;
- Direct discharges via sewage or intensive farm units (Whitehead *et al*. 1998);
- Unsaturated zones (Goolsby *et al*. 1999);
- Leaching from soil and industrial waste disposal sites (Singh *et al*. 2005);
- Municipal and industrial effluents (Singh *et al*. 2005);
- Agricultural runoff (Singh *et al*. 2005);
- Soil leaching and runoff process (Singh *et al*. 2005)
- The documented sources of chloride into a river basin include:
- Road salt (Kelly *et al*. 2010; Kelly *et al*. 2008; Boutt *et al*. 2001)
- Septic systems (Boutt *et al*. 2001);
- Locations of oil brine fields (Boutt *et al*. 2001); and
- High density human populations (Boutt *et al*. 2001)

- A survey was recently conducted to establish if any of these exist in the upper Kat River Basin. The factors that have a potential to impact the quality of water in the upper Kat River, as highlighted in literature, are presented in the discussion that follows.

Potential sources of nutrients in the study area

Vegetation clearance

Evidence exists in the upper Kat River of vegetation clearance in recent years. Vegetation had to be cleared in the area to make room for the new low-income dense residential area in Seymour. As was noted earlier, Turner and Rabalais (2003) blamed the increased nutrient loading in the Mississipi River Basin, though to a lesser extent, on the land drainage and the clearance of native vegetation to make way for cropland and grazing pastures. Haynes and Michalek-Wagner (2000) identified the minimization of vegetation clearance as one of the two activities necessary for the maintenance and protection of the quality of water in the Great Barrier Reef World Heritage Area, in Queensland, Australia. The other activity named here is the controlled application of fertilizer and pesticides (Haynes and Michalek-Wagner, 2000).

Residential settlements and urban runoff

Plate 4.1 shows the close proximity of the settlements in the upper Kat River area to the Kat River Dam. As was noted earlier, Lee *et al*. (2008) suggested that the higher nitrate concentrations in the South Han River, compared to the upper reaches was originating from the extensive distribution of agricultural fields, residential areas and animal farms in this part of the drainage basin. Adekunle *et al*. (2007) linked the elevated concentrations of coliform population, lead (Pb), nitrate (NO_3), and cadmium (Cd) in the groundwater in south-western Nigeria to the typical rural land-use. Another feature of concern of the new settlement in the study area is its position in relation to the terrain. The settlement is located on a slope overlooking the dam. The dirt roads together with the small channels running through the settlement become runoff water pathways that connect the settlement to the river. Thus, even the furthest part of the settlement is connected to the river through these runoff pathways. Some runoff pathways (Plate 4.1) appear to be flowing continuously, transporting raw sewage from one or more burst pipes in the settlement into the dam. The contribution of runoff water to the depreciation of quality of the surface water bodies is well-documented. For example, Fatoki *et al*. (2001) blamed runoff water from several settlements along the Mthatha River for elevated nutrient levels and high coliform count in the Mthatha River.

Plate 4.1: A runoff pathway through the newly-constructed low-income residential area

Livestock farming and riparian grazing

Livestock farming is popular in the upper Kat River area. The most common livestock are cattle and goats (Plate 4.2). While most of the households keep only a handful of these farm animals, these animals all graze on the Kat River's riparian zone. Their collective impact could, thus, be significant. For example, as was noted earlier, Lee *et al*.(2008) identified the animals farms as one of the three most significant contributors to the nitrate enrichment of the South Han River, compared to the upper reaches.

Plate 4.2: Livestock farming in the upper Kat River

Other factors of concern in the upper Kat River Basin include sanitation (Plate 4.3). While most households are connected to the septic tank, some are still using pit latrines. Others have no form of toilets. They are thus using the riparian environment to relieve themselves. Many authors have linked lack of sanitation to the microbial degradation of both the coastal and surface water resources. For example, Fatoki *et al*. (2001) blamed the high feacal count in the Mthatha River to the lack of sanitation of some riparian communities on the course of the river. In a more recent study, Clasen *et al*. (2007) realized that, the interventions of improving the microbial quality of water had positive implications on the reduction of diarrhea across the 21 countries that were compared.

Plate 4.3: Other factors of concern in the upper Kat River - latrines (L) and graves (R) in close proximity to the river

Among many other factors of concern is a grave yard, which is in very close proximity to the dam (Plate 4.3). The grave yard appears to be still active, with some burials having taken place recently. So close is the grave yard to the reservoir that when the river is in floods, some graves get submerged by the dam water. The community members indicated that, human remains (bones) have been repeatedly spotted on the shore of the dam, especially after the floods. Nutrients, pathogenic bacteria, viruses, protozoa, and helminthes are some the pollutants identified by Engelbrecht (1997) as introduced from the gravesite into the groundwater.

Sources of chloride

Septic tank system and high density residential settlements

As was noted earlier, the documented sources of chloride in literature include: road salt (Kelly *et al*. 2010; Kelly *et al*. 2008; Boutt *et al*. 2001); septic systems (Boutt *et al*. 2001); locations of oil brine fields (Boutt *et al*. 2001); and high density human populations (Boutt *et al*. 2001). Two of these identified sources exist in the upper Kat River. These are: septic systems and high density populations (Plate 4.4). Reay (2004) further blamed the elevated mean dissolved inorganic phosphorus (between 294 and 336 mol/l); dissolved inorganic nitrogen concentrations (4494 to 5391 mol/l); and the mean fecal coliform bacteria densities ranging from $10^{5.04}$ to $10^{6.29}$ 100 ml/l on septic tanks. Mallin *et al*. (2000) observed a strong correlation between the abundance of the fecal population and the watershed population. They also observed an even stronger correlation between the fecal coliform abundance and the percent of the total impervious surface in a watershed, including roofs, roads, driveways, sidewalks, and parking lots (Mallin *et al*. 2000).

Plate 4.4: The septic tank system (L) and high density housing (R) in the upper Kat River area

4.6.2.B The Balfour River site

As was reported earlier, a statistically significant reduction in the levels of calcium (α = 0.007), electrical conductivity (α = 0.000), sodium (α = 0.000), sulphate (α = 0.000), and pH (α = 0.000) was observed in the Balfour River site. A survey conducted in this part of the catchment area in an attempt to understand these trends revealed that a part of the land in the Balfour River basin, that was previously intensively used for commercial cropping had been lying fallow for some time. Also, most fields along the Balfour River had not been cultivated for some time (Plate 4.5). By implication, there has been a significant reduction in the loads of fertilizer and other agro-chemicals that were continuously applied on the crop lands in the Balfour River sub-catchment. Also, the significant reduction in the amount of land under irrigation-supported crop farming has two implications. The first is the reduction in the amount of water drawn from the river for irrigation. The second is the reduction in runoff generated and also less infiltration of the agro-chemical loaded irrigation water into the water table.

Plate 4.5: Land that was once used for crop farming lying fallow in the Balfour River area

The application of different types of fertilizers on crop lands has been blamed as a source of nitrate in many basins globally. To mention a few: Lee *et al*. (2008) identified manure as one of the primary sources of nitrate in the Haan River watershed, in Korea. Shrestha and Kazama (2006) had made similar findings in Japan earlier; blaming the nutrient enrichment of the Fuji River on non-point sources, which they identified as agricultural practices and orchard plantations. As was noted earlier, Turner and Rabalais (2003) identified the intense and widespread farming, and especially fertilizer use as the latest source of nutrient loading in the Mississipi Basin. While working on the upper parts of the same basin (Mississipi) earlier, Randall and Muller (2001) identified row-crop production as the primary source of nutrients loads into the river. Water from the artificially drained agricultural soils is one of the three factors blamed by Deutsch *et al*.

(2006) as the major sources of nitrate in a sub-basin in Germany. The other two are groundwater and atmospheric distribution. It, therefore, is not surprising that the quality of water in the Balfour River has improved since the abandonment of the crop production practices in the sub-catchment.

4.6.2.C The Fort Beaufort site

A comparison of the water quality condition of this site is presented in Tables 4.9 (nutrients) and 4.11 (salinity). As was reported earlier, Table 4.9 indicates a decrease on average on the levels of all four nutrient variables (calcium, potassium, ammonium, and nitrate) assessed during the 2001 – 2010 decade compared to the 1991 – 2000 decade. On the other hand, with the exception of pH, all other salinity variables (chloride, conductivity, sodium, and sulphate) were higher in the 2001 - 2010 decade compared to the 1991 – 2000. As was noted earlier, both changes in nutrient levels and salinity levels were not statistically significant in this site, in spite of the noted increase in intensive irrigation and agro-chemicals-supported citrus farming by about 20 percent between 2007 – 2011 period, as reported in chapter 3 (Table 3.3). The observations conducted in the study area uncovered a number of factors to which this scenario could be attributed. These are presented in two categories, which are: the best management practices (BMPs) implemented in land under the commercial citrus farming, and other factors. The sections that follow present a discussion on each of these factors.

The best management practices (BMPs) in the commercial citrus land

According to Sheridan *et al*. (1999), the on-site BMPs are known to reduce the transportation of pollutants from agricultural sources into the water systems. In the upper middle reaches of the Kat River basin, the on-site BMPs include: the micro-sprinklers in land under citrus (Plate 4.6); dense riparian vegetation (Plate 4.6); and a buffer zone – between the citrus and river. Phocaides (2000: 115) describe the micro-sprinklers as the ‘low capacity water emitters, sprinkler in type, but smaller in size than the conventional sprinklers and with flow rates up to 250 litres/h’. The efficiency of these ‘highly reliable, highly efficient, and easy to apply, operate, and handle’ (Phocaides, 2000: 115) is maximized when crops are densely planted. Ayars *et al*. (1999) identified the environmental benefits of using the micro-irrigation system as follows: first is the improved water and nutrient management. Second, micro irrigation allows the user a greater control and flexibility on the quantity of applied water. This results in lesser nutrient and water losses (Ayars *et al*. 1999). To that effect, Gardenas *et al*. (2005: 220) noted that 'micro-irrigation systems can be designed and operated so that water and nutrients are applied at a rate, duration and frequency, so as to maximize crop water and nutrient uptake, while minimizing leaching of nutrients and chemicals from the root zone of agricultural fields'.

Plate 4.6: Micro-sprinklers (L) and dense riparian vegetation buffer (R) in land under intense commercial citrus production in the middle reaches of the Kat River

The implication is the reduced water and nutrient requirements, resulting to lesser chances of runoff generation from the crop lands and, consequently, less nutrient loads getting into groundwater (through deep percolation) and surface water bodies (through runoff). It thus is not a reason of alarm that the quality of water between the Kat River Dam site and the Fort Beaufort site seem to improve. Ayars *et al*. (1999) also noted the economic benefits of these systems in the form of improved crop yields as well as crop quality.

The dense riparian vegetation and a good buffer zone (an average of 37.69 metres) between the citrus farms and the Kat River (Plate 4.7) could also be partly be responsible for the downstream improvement of Kat River water quality between the Kat River Dam and the Fort Beaufort sites. Spalding and Exner (1993) observed that, the aquifers in the eastern US, though in a highly agricultural area, remain uncontaminated. They attributed this scenario largely to the uptake of nitrogen by the abundant natural vegetation in these areas (Spalding and Exner, 1993). Dosskey (2001) identified the five ways by which buffer functioning can reduce non-point source water pollution from an agricultural crop land. These are: first, buffer zones, by allowing more time for infiltration, reduce runoff. Secondly, buffer zones serve to filter runoff. Thirdly, buffer zones filter the groundwater runoff. Buffer zones also serve to reduce bank erosion, while also filtering the stream water. (Dosskey, 2001). It is thus a possibility that, both the dense riparian vegetation along the Kat River and the buffer zone between the citrus farms and the river, play a significant role in minimizing the runoff, and also minimizing its impact on the quality of the Kat River.

Other factors that could impact the water quality status of the Kat River

Several other factors that could be partly blamed for the water quality situation in the Fort Beaufort site were identified. These include: abandoned crop lands; the dilution effect from the Fairbairn River, Balfour River, and Blinkwater Rivers; and the fact that, some farms are still new. Plate 4.7 presents a pictorial evidence of the abandoned land formerly used for intensive crop farming. As documented in the sub-section dealing with the water quality situation in the Balfour River catchment, there is documented evidence that crop farming affects the quality of water in the nearby water courses. When this land use activity therefore is discontinued, improvements in the quality of water may be observed from those basins.

Plate 4.7: Land in the upper middle reaches formerly used for intensive commercial farming (L) lying fallow and the decaying irrigation infrastructure (R)

As noted earlier, three big tributaries join the Kat River between the Kat River Dam site and the Fort Beaufort site. These are: Fairbairn, Balfour, and Blinkwater. The water quality improvements in the Balfour River during the 2001 – 2010 decade were highlighted earlier. In view of the fact that, most development in the study area is concentrated around the Kat River, there is a possibility that the other two tributaries (Fairbairn and Blinkwater) also have lower concentration of nutrients and salts than the main Kat River. Thus, in addition to enjoying the dilution effect from the Balfour River, the Kat River water may also be getting diluted with the water from the other two tributaries. D'Arcy and Frost (2001) identified the use of dilution to improve the quality of water in a basin as one of the three primary elements of the environmental quality standards (EQS). The other two are: one or two key pollutants that can be modeled and will accurately reflect the properties of the discharge, and a robust environmental quality standard for each of the key pollutants (D'Arcy and Frost, 2001).

Another factor worth considering is the fact that, the expansion in citrus in the Kat River catchment is still new (the process being initiated in 2007, and the first farm late in

2007). In 2010, the final year in the water quality analysis, the farms were only 2 years in operation. And in 2013, some lands were just being developed (Plate 4.8).

Plate 4.8: New citrus development (2013) in the Kat River valley

In view of the literature evidence presented earlier, the role of each of the factors identified above, as well as the collective contribution in improving the quality water in the middle reaches of the Kat River is noted.

4.7 Conclusion and recommendations

In this chapter, a summary of the results of an investigation on the impact of the Kat River Valley Water User Association on the salinity and nutrient status of the Kat River in the first decade since its establishment are presented. Following are the objectives of the study that were earlier adopted so as to realize the aim of the study.

- examining the impact of institutional change on the salinity and nutrient status of the Kat River water;
- establishing if the nutrient status of the Kat River is different in the period between 1991 – 2000 and 2001 – 2010;
- Establishing if the salinity status of the Kat River is different in the period between 1991 – 2000 and 2001 – 2010

This study was an attempt to answer the following research questions:

- Is there a significant difference in the nutrient status of the Kat River water before and after the establishment of the Kat River Valley Water Users Association?
- Is there a statistically significant difference in the nutrient status of the Kat River water in a decade before (1991 – 2000) and a decade after 2001 – 2010) the establishment of the Kat River Valley Water Users Association?
- Is there a statistically significant difference in the salinity status of the Kat River water in a decade before (1991 – 2000) and a decade after (2001 – 2010) the establishment of the Kat River Valley Water Users Association?

To address the above research questions, a 20 year water quality data of the three monitoring points on the Kat River and Balfour River was obtained from several sources. After clean-up, and pre-processing, the data was divided into two decades (1991 – 2000 and 2001 – 2010), a paired-samples t-test was conducted to compare the means of the two decades of the several water quality variables measuring both the nutrient status of the river (calcium, potassium, ammonium, nitrate) and the salinity status of the river (chloride, electrical conductivity, sodium, sulphate and pH).

The findings of the study can be summarized as follows:

- A statistically significant increase ($\alpha = 0.05$) in the levels of calcium, potassium, ammonium, nitrate, and chloride was observed in the Kat River Dam site during the 2001 – 2010 decade, compared to the 1991 – 2000 decade;
- A statistically significant decrease ($\alpha = 0.05$) in the levels of calcium, chloride, electrical conductivity, sodium, sulphate, and pH was observed at the Balfour River site.
- No statistically significant difference ($\alpha = 0.05$) was observed between the means of the two decades in the Fort Beaufort site.

The objectives of the study were therefore realized. For both the Kat River Dam and the Balfour sites, the null hypothesis, stating that there is no difference in the water quality means of the two decades is rejected, and the alternative, accepted. In the Fort Beaufort site though, since no significant difference was observed, we fail to reject the null hypothesis stating that, there is no significance difference between the water quality means of the 1991 – 2000 and 2001 – 2010 decades. The aim and objectives of the study were therefore realized.

However, a water quality study, focusing specifically on the upper reaches of the Kat River (rather than the entire basin), is required to assess the impact of each of the factors identified in this study to be possibly impacting the quality of the Kat River water. To minimize the impact of all the factors identified in the study to be possibly impacting the quality of the Kat River water, following recommendations are presented:

- In the upper reaches, an effort must be made to ensure that runoff transporting the non-point source pollution is managed. Structurally, this could mean constructing an artificial wetland though which runoff will be allowed to run, in the process, delaying the delivery of the runoff to the river, whilst also purifying it. Another structural possibility would be a construction of a detention pond that will temporarily trap runoff, allow some of the materials transported to settle down and some elements to reach at least their half-life. After which, the runoff could be released into the river, in a far less harmful state to aquatic life as well as the downstream water users. To supplement these structural ways of managing the non-point pollution, some environmental education workshops can be conducted to enlighten the communities in this part of the catchment about the environmentally-friendly practices that could benefit them (communities) and also assure them of a cleaner natural environment around them.
- Fencing is required along the river in the upper reaches to protect animals from drowning into the Kat River Dam, and also minimize and maybe, control the access of livestock to the river.

- Each household must be provided with an environmentally friendly toilet system. This would avoid the environmental challenges associated with the use of pit latrines (e.g. groundwater pollution), and also those associated with communities without any form of a toilet facility (e.g. the high pathogen count).
- The graveyard must immediately be closed, cleaned, and moved further away from the river as a matter of urgency.
- An extra effort must be made to ensure that, the frequency of draining the septic tank is increased to ensure that it never fills to the extent of overflowing. Due to the close proximity of the septic tank to the river, and the slope on which it is located, any spills of raw sewage from the septic will definitely get into the river. Also, a new site further away from the river must be found for the septic, on a surface that is sloping away from the river. Also, due to the environmental problems associated with the septic tanks, this option of sewerage management must be replaced with a more environmentally friendly system, the conservancy tanks.

CHAPTER V

GENERAL CONCLUSION

5.1 General conclusion

The overall purpose of this study is to assess the impact of the change of the water management institutions on the Kat River water quality in the first decade since this change was effected. The year 2010 marked the tenth year of this change in the Kat River Valley. In 2000/1, the water management responsibilities in the Kat River were transferred from the former predominantly white Kat River Irrigation Board to the newly-formed all-encompassing stakeholders-based Kat River Valley Water Users Association (WUA). Specifically, the change in the salinity and nutrient status of the Kat River water is assessed. In Chapter 1 (General Introduction), the following objectives of the study, and their related research questions were presented:

- assess land-use change in the Kat River valley between 2001 and 2011 (addressed in Chapter 3);
  - Has there been any noteworthy land-use change in the Kat River valley since 2001?
- examine the impact of institutional change on the salinity and nutrient status of the Kat River water (addressed in Chapter 4);
  - Is there a significant difference in the salinity and nutrient status of the Kat River water before and after the establishment of the Kat River Valley Water Users Association?

In Chapter Two (Description of the Study Area), the context of the study was set. For example, the average annual rainfall of 400mm in the immediate vicinity of the biggest urban center in the basin (Fort Beaufort) is below the South Africa’s annual rainfall average (around 450mm). Fort Beaufort is located in the lower middle reaches of the basin. It is also crucial to note that the middle reaches and the lower reaches of the basin are the most land-use intense parts of the basin. For example, all commercial citrus farming is located on these parts of the basin. As was noted earlier, the biggest urban center in the basin (Fort Beaufort); the dense low income peri-urban Balfour settlement; as well as the only urban township in the basin are located along the middle reaches of the basin. Several rural human settlements are also located in these parts of the river. The implication of the lower average annual rainfall in the context of the study, is the heavy reliance of all these land use and related activities on the water of the Kat River and its tributaries for sustenance. It is, therefore, logical to conclude that the management of the Kat River basin water is crucial to the livelihood of both the farming, rural, peri-urban, as well as the urban communities along the river.

The ‘historical background to the study area’ section portrays the Kat River valley as an area dominated through the centuries, by racial conflicts, leading to animosity among the different racial groups that inhabit the basin. This is evidenced by the many battles that were fought among the amaXhosa and the White racial groups in the basin, with the Coloured communities, at some stage being used as human shields to protect the Whites against amaXhosa. In fact, to this day, several landmarks (army forts and graves of traditional leaders who died during some of those battles now commemorated as the national monuments etc) still bear witness to these wars.

As was noted earlier, in chapter 3, the first of the two objectives listed earlier (assessing land-use change in the Kat River valley between 2001 and 2011) was addressed. Specifically, an attempt was made to establish if there has been any noteworthy change in land use in the Kat River valley between 2001 and 2011). Land use in the study area was classified into six categories, which are: water bodies; forest land; citrus land; built environment; rangeland; and bare/barren surfaces. With the exception of the citrus land, for all other land use classes, the Anderson *et al*. (1977)’s definition of each was adopted. The citrus land is not defined as a stand-alone land use in Anderson *et al*. 1977’s classification system. The prominence of this land use activity in the area necessitated that it be defined as a stand-alone land use class in this study. In view of that realization, the definition of this activity, as proposed by the USDA (2012), was adopted.

From the analysis of the 2001, 2007, and 2011 SPOT satellite images (also presented in chapter 3), the following noteworthy trends emerged: the area covered by the water bodies dwindled from 2.9 percent in 2001 to 1.3 percent in 2011; the area covered by built environment increased from 2.2 percent in 2001 to 5.5 percent in 2011; the surface area of bare surfaces increased to 34.5 percent in 2007, from 19.4 percent in 2001, and dropped again to 19.5 in 2011; the forest area increased to 27.8 percent in 2011, from 15.2 percent in 2001; citrus land got smaller to 13.7 percent in 2007, from 22.9 percent in 2001, but had gone up again to 16.4 percent in 2011; rangeland got smaller to 25.6 percent in 2007 from 37.5 percent in 2001, but increased again in 2011 to 29.6 percent.

The discussion section (Section 3.4) in that chapter is devoted on explaining these trends. The observations conducted in the study area as well as the documented literature are used to explain the observed trends in the study area. For example:

- Most of the land that was intensively used for cropping vegetables and other crops in the upper catchment in 2001, was lying fallow in 2013.
- Vegetation clearance in some of the old citrus farms that lay fallow in 2001 had started to happen by 2007 as the farms were being re-developed to be active in citrus production. In 2011, an even greater amount of land was cleared and being developed in the upper middle, middle and lower middle reaches of the Kat River Valley. Citrus trees were being planted, irrigated, and agro-chemicals were being applied. These activities would explain the reduction in rangeland and a corresponding increase in bare land. Since it takes up to five years for citrus trees to grow in full, the newly developed citrus farms would continue being sensed as bare surfaces by the satellites. It would however be expected that as these trees grow bigger, the bare land class gets smaller. This is a possible explanation for the 2.7 percent increase in citrus land area between 2007 and 2011.

- The dwindling water resources in the study area could be as a consequence of a seemingly, re-awakened interest in agricultural activities (livestock farming and cropping) as evidenced by the increases in rangeland and commercial faming between 2007 and 2011.
- The increase in built environment could largely be attributed to the recently built low-income residential area in Seymour and the natural expansion of almost all the rural settlements in the area. Evidence also exists of the new development in the central business district of Fort Beaufort since 2001.

Documented literature is used to identify the possible negative effects those land use changes could have on the natural environment, especially the Kat River and its environment. The noted possible impacts of land use change on the natural environment are documented in literature as follows:

- Affecting the fertility properties of the soils (Emadi *et al*. 2009; Verburg *et al*. 2006); as well as the elevated erosion risk of the soils (Schiettecatte *et al*. 2008);
- Positive and negative impacts on the ecosystem integrity of a habitat (Jepsen *et al*. 2005);
- The effect on several hydrological factors and properties, including: a change in crop management factor (Schiettecatte *et al*. 2008), increased sensitivity to floods (Camorani *et al*. 2005), degraded groundwater, wetlands and surface water quality (Kulabako *et al*. 2007; Elmanama *et al*. 2006; Houlahan and Findlay, 2004; Pulamuleni *et al.* 2004; Berka *et al*. 2000; Haynes and Michalek-Wagner 2000);
- Masamba and Mazvimavi (2008) established a link between the organic matter and nitrogen pollution of the Thamakalane-Boteti River in the Okavango Delta, Botswana and the built environment (residential areas; lodges; hotels) as well as grazing by cattle and donkeys in that area.

It is thus evident from the information above that objective 1 was realized. The research question of whether there has been any land use change of note in the Kat River Basin is answered in affirmation. Documented literature seems to suggest that the observed land use change in the study area could have negative implications on the quality of water of the Kat River and its tributaries. Chapter 3 therefore provides further justification for a water quality study, presented in chapter 4 of this document.

Objective 2 (examining the impact of institutional change on the salinity and nutrient status of the Kat River water) is addressed in chapter 4. To realize this objective, water quality data for the three sites (Kat River Dam; Balfour River; and Fort Beaufort) covering a 20 year period (1991 – 2010) were obtained from several sources. After cleaning and pre-analysis of the dataset, the data were then divided into two decades, which are: the pre-2001 (1991 – 2000) and post-2000 (2001 – 2010). A paired-samples t-test was then conducted to compare the means of the two decades of the several water quality variables measuring both the nutrient status (calcium, potassium, ammonium, and nitrate) and the salinity status (chloride, electrical conductivity, sodium, sulphate and pH) of the Kat River Basin.

At the Kat Dam site, the post-2000 means for calcium, potassium, ammonium, nitrate, and chloride were significantly higher at 95 percent confidence level compared to the pre-2001 means. Overall, the quality of water appeared to be poorer during the post-2000 decade compared to the pre-2001 decade. At the Balfour River site, the post-2000 means of calcium, chloride, electrical conductivity, sodium, sulphate, and pH were significantly lower at 95 percent confidence level. Judging by the water quality results at this site, which is located downstream of most land use activities in this sub-catchment, it would appear logical to conclude that the quality of water in this catchment is improving. At the downstream-most site, the Fort Beaufort site, located just upstream of the Fort Beaufort town, no significant differences between the means of the two decades were observed at the 95 percent confidence level.

The observations in the study area revealed several factors to which the water quality trends presented above could be attributed. The degradation of water quality at the Kat Dam site could be attributed to the following prevalent factors in the part of the basin, immediately upstream of the study site:

- Vegetation clearance: blamed by Turner and Rabalais (2003) for the increased nutrient loading in the Mississipi River Basin, while Haynes and Michalek-Wagner (2000) linked the water quality improvement in the Great Barrier Reef World Heritage Area, in Queensland, Australia to the minimization of vegetation clearance.
- Residential settlements located in close proximity to the river, with runoff pathways from the settlements leading directly into the river: several authors have linked the poor quality of water to the impact of the settlements. For example, Lee *et al*. (2008) linked the elevated nitrate levels in the southern Haan River in China to residential areas and animal farms linked to the settlements. Adekunle *et al*. (2007) blamed human settlements for the elevated concentrations of coliform population, lead (Pb), nitrate (NO_3), and cadmium (Cd) in the groundwater in south-western Nigeria. Earlier, Fatoki *et al*. (2001) blamed runoff from several settlements along the Mthatha River, South Africa for elevated nutrient levels and high coliform count in the Mthatha River.
- Livestock farming and riparian grazing: animal farms are among the leading contributors of nitrate (Lee *et al*. 2008) levels so noticed.
- The septic tank and the dense residential areas were identified by many authors (Reay *et al*. 2004; Bout *et al*. 2001; Mallin *et al*. 2000) as the most significant sources of chloride.

The water quality improvements at the Balfour River were attributed to the dying off of the intensive irrigation, and agro-chemicals supported crop farming in the sub-catchment. The observed trends at the Fort Beaufort site could be attributed to many factors, which are: the best management practices (BMPs) in the land under commercial citrus farming. The BMPs used include the use of micro-sprinklers, which Phocaides, (2000: 115) refers to as‘highly reliable, highly efficient, and easy to apply, operate, and handle’; dense riparian vegetation between the citrus farms, and the river. Both these were found to be effective in reducing the pollution of water. Gardenas *et al*. (2005: 220) noted that ‘micro-irrigation systems can be designed and operated so that water and nutrients are applied at a rate, duration and frequency, so as to maximize crop water and nutrient uptake, while minimizing leaching of nutrients and chemicals from the root zone of agricultural fields’. Ayers *et al*. (1999) noted that micro-sprinklers allow improved water and nutrient management, whilst also reducing nutrient and water losses. Spalding and Exner (1993) recognized the role of the riparian vegetation in uptaking the nutrients. Also, according to Dosskey (2001), riparian vegetation enhances the infiltration capacity of the soil, while also filtering runoff among others.

Other factors that could impact the quality status of the water of the Kat River are:

- The dilution effect, where the Kat River is joined by the other less polluted tributaries; and
- The fact that most of the citrus development in the Kat River is still too new for any of its effects to be observed.

In the light of that information, one can only conclude that the objectives of this study were realized. For both the Kat Dam and the Balfour River sites, significant differences between the means of the pre-2001 and post-2000 decades for most of the variables were observed.

A detailed list of recommendations in chapter 4 is presented in sub-section 7 of that chapter. In summary, they are:

- Structural measures be put in place for runoff management (artificial wetands, detention ponds etc);
- Fencing of the riparian environment to keep animals away from the river;
- Environmentally friendly toilets be provided for each household;

- Grave yard be relocated away from the river;
- Septic tanks be drained at a higher frequency and be replaced with conservancy tanks, to be located away from the river.

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