IMPLICATIONS OF LAND USE PRACTICES AND SOCIO-HYDROLOGICAL VULNERABILITY WITHIN A RAPIDLY DEVELOPING CITY: A CASE STUDY OF THE UMHLATUZANA RIVER, ETHEKWINI, SOUTH AFRICA

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PREFACE

The work described in this dissertation was carried out in the School of Agriculture, Earth and Environmental Sciences, University of KwaZulu-Natal, Westville campus from June 2014 to September 2020, under the supervision of Dr Suveshnee Munien and Prof Sershen Naidoo. The study represents original work by Candice Natasha Webster and has not otherwise been submitted in any form for any degree or diploma to other tertiary institutions. Where use has been made of the work of others, it is duly acknowledged in the text.

DECLARATION – PLAGIARISM

I, Candice Natasha Webster (Student no: 210528703), hereby declare that:

- The research reported in this dissertation, except where otherwise indicated, is my original research.
- This dissertation has not been submitted for any degree or examination at any other university.
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ABSTRACT

Anthropogenic actions affect land uses and land use change concomitantly influencing water quality in a catchment. In a catchment varying levels of income and access to infrastructure and resources result in a lack of access to reliable and clean water, forcing households to rely on nearby water sources such as rivers, dams or lakes to meet their basic needs. Utilisation of river water is influenced by the perception of water quality. The main aim of this study is to explore how land use practices and human-water interactions influence socio-hydrological vulnerability within the Umhlatuzana catchment in a rapidly developing city. Previous research has not focused on the water quality and vulnerability of households within South African catchments. Land use activities and land use changes were observed between 2003 and 2014 to examine the pressures on water and water quality in the catchment. Furthermore, selected water quality parameters were analysed for an 11-year period between 2004 and 2014 in order to examine temporal and spatial variation to unpack influences on vulnerability in the catchment. Moreover, 350 household surveys were administered in order to describe the community perception of land use, land use change and water quality in the catchment. Finally, field observations of areas surrounding the water sampling sites were completed to inform results, and provide a more nuanced understanding of data trends, community perceptions, and experiences with the river. Analysis of the spatial data indicates changes in the catchment that may contribute to the deteriorating water quality in the river. Furthermore, reports of malfunctioning Waste Water Treatment Works (WWTW) link the sewage system to increasing *E. coli* and *T. coli* levels in the river, which threatens the health and well-being of all river users. The households in the community are diverse with varying levels of vulnerability and access to resources as many households identified government grants as a source of income. Additionally, although most households perceived the river water in the catchment to be poor and deteriorating, of those that utilised the river water, majority did not treat it before use. The study demonstrates that there are households within the catchment that are vulnerable and at risk to the deteriorating river water in the catchment. Further research is required to identify sources of pollution to improve the water of the Umhlatuzana River and reduce risks to the community in the catchment.

Table of Contents

LIST OF FIGURES

LIST OF IMAGES

LIST OF TABLES

LIST OF ACRONYMS

BOD	Biological Oxygen Demand
CFU	Coli Forming Units
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
D’MOSS	Durban Metropolitan Open Spaces System
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EC	Electrical Conductivity
E. coli	*Escherichia coli*
EMA	eThekwini Municipal Area
GCIS	Government Communication and Information System
GEAR	Growth Employment and Redistribution
GIS	Geographic Information Systems
KZN	KwaZulu-Natal
L	Litres
LC	Lower Catchment
MC	Middle Catchment
MDG	Millennium Development Goals
MG	Milligrams
ML	Millilitres
mSm/m	Millisiemens per meter
NTU	Nephelometric Turbidity Unit
pH	potential of Hydrogen
PPP	Public-Private Partnership
PV4	Permanganate Value
RDP	Reconstruction and Development Programme
RWQI	River Water Quality Index
SAWQG-DU	South African Water Quality Guidelines- Domestic Use
SAWQG-RU	South African Water Quality Guidelines- Recreational Use
SDG	Sustainable Development Goals
SPSS	Statistical Package for Social Science
StatsSA	Statistics South Africa
STS	Septic Tank Systems

T. coli	*Total Coliform*
TDS	Total Dissolved Solids
UC	Upper Catchment
UN	United Nations
UNICEF	United Nations Children’s Fund
USA	Unite States of America
WHO	World Health Organisation
WSA	World Summit Awards
WWAP	World Water Assessment Programme
WWF-SA	World Wildlife Fund for Nature- South Africa
WWTW	Waste Water Treatment Works

CHAPTER ONE
INTRODUCTION

1.1 Preamble

At the close of the Millennium Development Goals (MDGs) in 2015 approximately 663 million people, globally, still lacked access to improved drinking sources (World Health Organisation [WHO] and United Nations Children's Fund [UNICEF], 2015). Additionally, 2.4 billion people were without access to reliable sanitation facilities and approximately 1 billion people lacked access to safe drinking water (Ridoutt and Pfister, 2010; WHO and UNICEF, 2015). The demand for freshwater is expected to rise particularly in developing countries where water is a key input for manufacturing, electricity generation and domestic use (World Water Assessment Programme [WWAP], 2014). Of the global aquifers, an estimated 20% are overexploited as groundwater extraction increases by one percent annually (Gleeson *et al*., 2012). Increased groundwater extractions, climate change related threats, and population growth has resulted in growing pressure on global freshwater sources (Ridoutt and Pfister, 2010; WWAP, 2014). Freshwater suitable for human consumption is scarce and often distributed along economic class, racial and gender lines, resulting in an inequitable distribution (Gleditsch *et al*., 2006; Mahlanza *et al*., 2016). This trend coupled with the increase in demand for freshwater highlights the need for an integrated resource management strategy to ensure the availability of sufficient and clean water.

Infrastructure and its associated maintenance are not the only barriers associated with access to water, it is also necessary to address issues of management and distribution. The 1996 Bill of Rights, according to the South African Constitution, stipulates that all people have the right to sufficient water, which implies that water is a legal entitlement and not simply a commodity or service (Debbane and Keil, 2004; Allen *et al*., 2006a; Karunananthan, 2019). Although noted as a basic human right, the provision of water resources is inequitably distributed amongst citizens. This process has become increasingly privatised due to the devolvement of political duties and responsibilities to local governments who rely on revenue collected from levies placed on properties within its jurisdiction to ensure cost recovery, financial sustainability and service delivery (Gleditsch *et al.*, 2006; Tshandu and Kariuki, 2010; Mirosa and Harris, 2011). Consequently, lower-income communities often lack access to adequate and reliable water and sanitation services when compared to more affluent areas as they are unable to afford the costs of access, which are often set at market prices (Obeng-Odoom, 2011). In South Africa, there are 21 water source areas with more than 500 government owned dams from which the country uses approximately 10.2 billion m^3 of water a year (World Wide Fund for Nature South Africa [WWF-SA], 2016; Department of Government Communication and Information System [GCIS], 2018). The provision of water sources, nationally, is the responsibility of municipal Water Service Authorities (WSA) (WWF-SA, 2016). Physical and financial access to water sources is not the only challenge, as there are additional complex issues pertaining to the quality and quantity of water available to communities.

The provision of water of an adequate quality is of importance for domestic use as impure water containing biological and chemical pollutants pose a serious threat to human health (Obeng-Odoom, 2012; Gain *et al*., 2016). The lack of access to water is expected to contribute to the spread of infectious diseases and may further undermine improvements of health and hygiene (Howard and Bartram, 2003; Motoshita *et al.,* 2011). In 2000, the Free Basic Water Policy of South Africa specified that 25 litres (L) of free and safe water be provided per person per day, amounting to 750 L per month per person (Abrahams *et al*., 2011; Mirosa and Harris, 2011; Karunananthan, 2019). Insufficient access to adequate quantities of potable water increases dependence on unreliable sources, which are often located closer to one's place of residence (Adler *et al*., 2007).

Although there has been a decrease of informal settlements in urban South Africa (Statistics South Africa [StatsSA], 2016) the presence of these settlements is a major problem in developing countries and across the globe given the poor living conditions (Hope, 2009). Limited infrastructure, particularly in informal and peri-urban communities, increases the likelihood of communities depending directly on water bodies for their agricultural, domestic and sanitation needs (Allen *et al*., 2006*a*). Furthermore, these informal settlements are often situated on marginalised land, which tends to be ecologically fragile and unsuitable for essential infrastructural development (Okurut *et al*., 2014). Limited access to clean water and sanitation infrastructure and services at the household levels, endanger community health and well-being (Hope, 2009; Okurut *et al*., 2014).

1.2. Motivation for study

The land use patterns within an area are influenced by natural and socio-economic factors that may change over temporal and spatial scales. Land use is often defined in terms of the anthropogenic activities that alter and threaten surface processes such as hydrology and biodiversity (Allan, 2004; Sajjad and Iqbal, 2012). Rural, urban and industrial land use practices have various effects on river systems. Studies on agricultural land use highlight the detrimental effects of pesticides and artificial nutrients on nearby water bodies (Allan, 2004; Parris, 2011; Shi *et al*., 2017). Industrial land use is usually related to the discharge of industrial waste (Tu, 2011). The composition of this discharge is dependent upon the nature of the industry and may consist of organic, heat, and chemical pollution amongst others (Schwarzenbach *et al*., 2010; Kanu and Achi, 2011). Urban land uses may contribute to both point and non-point source pollution as impervious surfaces may transport pollutants to waste water treatment works that discharge into rivers or may transport pollutants directly into streams or rivers (Yu *et al*., 2016; Shi *et al*., 2017).

Developing countries are increasingly associated with decreases in rural land use activities and an increase in urban land use due to increased rates of urbanisation and the expansion of the peri-urban zones due to rural-urban migration (Hope, 2009; Sajjad and Iqbal, 2012). Land use changes related to urbanisation, industrialisation and agriculture could influence the quality and quantity of river systems within a water catchment given that sources of degradation may emanate from a single identified source, or from multiple unidentified sources (Seeboonruang, 2012). Pollution from multiple sources reduce the possibility of identifying the source of contamination thereby hindering effective catchment management plans (Seeboonruang, 2012; Tsaboula *et al*., 2019). Furthermore, urban and peri-urban land uses are perceived to contribute to the degradation of water sources due to discharge of human sewage (Tu, 2011).

Moreover, peri-urban developments are often associated with urban centres, typically comprising a mixture of land uses characterised by both urban and rural livelihood practices (Parkinson and Tayler, 2003; Thornton, 2008; Wandl and Magoni, 2016). The combination of these land uses results in development being in constant transition which may increase the likelihood of social and environmental tensions (Parkinson and Tayler, 2003; Pinto and Maheshwari, 2014). Peri-urban communities are often of varying economic status with households of lower incomes lacking the political and economic power or resources to improve their access to water and sanitation (Allen *et al*., 2006b; Kubanza and Simatele, 2016). Coupled with neglect by administrative authorities poorer peri-urban communities lack formalised urban planning. This is evident in the inadequate access to infrastructural facilities such as piped water supply and sanitation and may result in a deteriorated state of the environment (Douglas, 2006; Okurut *et al*., 2014).

Within South Africa, there is a need to take cognisance of the impacts of apartheid's inequity as well as the growth of the population which have resulted in the formation of sprawling informal settlements on the urban edge whose inhabitants are trapped in the cycle of poverty (Abdul-Azeez, 2018). The apartheid regime excluded the black African majority from accessing basic services such as water, education and sanitation (Debbane and Keil, 2004; De Kadt and Lieberman, 2017). Post 1994, water and sanitation provision was privatised as a means of recouping costs and ensuring sustainability in addition to service delivery, which resulted in significant backlogs in previously disadvantaged communities (Mirosa and Harris, 2011). Due to the political history of racial discrimination, South Africa is characterised by inequitable distribution and access to clean, safe and affordable water services and related infrastructure, resulting in an increased reliance on fresh and untreated water sources, particularly among the more vulnerable communities (Dungumaro, 2007).

Concerning the utilisation of a natural water source, this may be influenced by the community's perceptions of water quality and may be perceived to be a health risk based on its odour, colour, taste, and turbidity (Doria, 2010; Shaheed *et al*., 2014). These households may be characterised as vulnerable, hybrid water users, utilising both standpipes and nearby rivers or water bodies for domestic purposes (Dungumaro, 2007; Doria, 2010). Given the aforementioned, the quality of water consumed and the health of individuals are intrinsically linked, and therefore health becomes a growing concern within the peri-urban and informal sectors, specifically within developing countries. Moreover, South Africa recently experienced one of the most severe droughts in 23 years (Baudoin *et al*., 2017). Prolonged droughts, such as the one experienced between 2015 and 2016, are a threat to vulnerable communities as households experience water shortages (Muyambo *et al*., 2017).

Leaking of effluent or greywater into surface water bodies contaminates water sources with pathogenic bacteria such as *Escherichia coli* (*E. coli*) or other *Total Coliform bacteria* (*T. coli*) which are responsible for various gastrointestinal diseases and illnesses (Ishii and Sadowsky, 2008; Gomes *et al*., 2016). The Cholera outbreak of 2000, in KwaZulu-Natal (KZN), is an example of poor water treatment and inadequate sanitation which resulted in approximately 80 000 infections and 170 deaths (Debbane and Keil, 2004; Mirosa and Harris, 2011). In the period of 2018 to 2019, high *E. coli* levels have been recorded in the rivers and harbour within the eThekwini Municipal area (EMA) (Nxumalo, 2018; Rall, 2019). This has been linked to pump failures and malfunctioning wastewater treatment works (Nxumalo, 2018; Rall, 2019). The effects of contemporary issues such as climate change are expected to increase pressures on the health and well-being of communities; through droughts, floods, and to a lesser extent, shifting weather patterns. The rise in temperature provides a conducive environment in which pathogens may breed and cause an increased prevalence of water-borne diseases (Oberholster, 2010). When coupled with other health issues such as drug-resistant pathogens, individuals whose immune systems are already compromised may be at risk of infections, further undermining their quality of health (du Preez, 2010). Communities that are vulnerable to climate-related diseases such as malaria, changes in temperature and rainfall patterns, particularly in Africa, are projected to have increased incidences of vector-borne diseases (Hope, 2009; Campbell-Lendrum *et al*., 2015). More impoverished communities living in squalid conditions or those who are closer to surface water bodies will be most vulnerable as they often lack access to adequate health facilities (Hope, 2009).

The importance of sufficient access to clean water has previously been emphasised by the United Nations (UN) during the United Nations Millennium Summit in 2000; governments formed the MDGs in aspiration of rapid progress on developmental issues by the year 2015 (Benjelloun and Tarrass, 2012). At the close of the MDG period, 91% of the worlds' population gained access to improved drinking water, 2.9 billion people obtained access to improved sanitation, whilst the proportion of developing region slums declined to 29.7% (UN, 2015a). In light of these achievements, it is necessary to note that there are still millions of individuals without access to a sustainable clean water source and adequate sanitation (Bos and Brocklehurst, 2010; Tortajada and Biswas, 2018).

The Sustainable Development Goals (SDGs) was approved by the UN General Assembly in 2015, an extension of the MDGs, the SDGs have a broader focus intending to end poverty and hunger, foster peaceful, just and inclusive societies, ensure prosperity for all and, protect the planet from degradation (Cole *et al*., 2018). Of the 17 goals, SDG 6 is described as 'water and sanitation for all' and has been divided into a further 6 main targets: water quality; safe drinking water; water use efficiency and scarcity; access to sanitation; water resources management and water-related ecosystems (Cole *et al*., 2018; UN, 2015). The achievement of SDG 6 and its targets is essential for sustainable development and economic growth and is likely to improve health, sanitation and access to potable water (Cole *et al*., 2018). This study, in recognising the multiple factors contributing to social-hydrological vulnerability, premises that any success towards achieving this goal must adopt a systems approach at the catchment level, particularly in South Africa where large-scale discrepancies are prevalent along socio-economic and geographic gradients.

Peri-urban areas are often neglected, marginalised and may be delineated during national statistics according to population density and distance from core built-up areas (Allen *et al*., 2006a; Marshall *et al*., 2009). Administrative authorities governing peri-urban areas are usually extensions from rural or urban areas, and as such, they cannot adequately deal with issues that are inherently peri-urban (Allen *et al*., 2006b). Results of this poor administration are evident in the transport, energy, land use planning, water supply and sanitation sectors (Allen *et al*., 2006b). Poor administration, lack of political will and economic power within peri-urban communities, creates an environment where peri-urban households are vulnerable to the detrimental impacts of land use changes, poor water quality and sanitation (Allen *et al*., 2006b). In order to combat these challenges, the social and economic heterogeneity of these communities must be acknowledged (Montgomery, 2009).

Previous research has not focused on the water quality and vulnerability of households within South African catchments. This study focuses on lower-income households within peri-urban and urban settlements in both formal and informal settlements. In doing so, multiple theoretical/ conceptual frameworks have been chosen to guide this research process. In the South African context given the political history, the geographies of health theoretical framework was used to understand and unpack the influence of geography on health. In addition, when examining access to basic services, the place perspectives framework is relevant given the socio-economic diversity across the South African landscape. Since the abovementioned frameworks capture the external factors that influence household consumption and access to water, it was deemed necessary to include the socio-hydrology framework, which lends an understanding of the personal domain, and individual level factors that influence consumption, attitudes, and perceptions.

In order to determine the threats posed to these households, it is necessary to highlight the changes observed in the land use surrounding the water body being utilised over a long period. Long term monitoring of water quality and land use allows for the examination of spatiotemporal patterns and changes in the catchment. Reports of historical river degradation and poor water quality in eThekwini Municipality in the 2004 to 2014 period, motivates for a critical assessment of any changes. Understanding the interactions between land use, water systems and households will assist in improving the well-being and lives of the vulnerable groups highlighted above. Whilst this study examines the peri-urban context in relation to access to water resources, it also highlights some of the main contributing factors to socio-hydrological vulnerabilities within these systems by examining land use and water quality over the past 11 years. The study is guided by the research questions, aims and objectives as explained in the following section.

1.3. Research Questions

- What are the surrounding land use practices within the Umhlatuzana catchment and how do they influence water quality?
- What are the historic and current trends in water quality variables within the Umhlatuzana River?
- Are there spatial trends in terms of water quality and land use practices?
- What are the socio-demographics and health characteristics of the communities in the Umhlatuzana Catchment?
- How does the community utilise the adjacent water body, and how do their perceptions influence their use of the water body?
- What are the perceptions of water quality and its associated impacts?

1.4. Research Aim and Objectives

In addressing the above questions, the main aim of this study is to:

> Explore how land use practices and human-water interactions influence socio-hydrological vulnerability within a rapidly developing city.

The specific objectives formulated to achieve the aim and address the research questions are:

- *To assess how the water quality in the Umhlatuzana River has changed over an eleven-year period (2004-2014).*

Examining changes in water quality indicators are key in establishing risk exposure to potential users and the natural system itself. Select variables were chosen to determine health and environmental-related risk of the Umhlatuzana River.

- *To examine changes in land use practices and the impacts on select water quality indicators within the catchment during for the 2003-2014 cycle.*

The link between land use practices and water quality has been extensively established in the literature. By examining these linkages, this study hopes to provide a more robust understanding of the main factors influencing socio-hydrological vulnerability among peri urban dwellers within rapidly developing cities.

- *To profile selected communities within the Umhlatuzana catchment.*

The Umhlatuzana catchment is inhabited by households with diverse socio-economic backgrounds with variations in levels of education, access to water and sanitation, employment and monthly income. Establishing socio-demographic profile permitted a deeper understanding of how different groups respond and/ or cope with socio-hydrologic stresses.

- *To examine the community's use and perceptions of the Umhlatuzana river and the perceived determinants and impacts of water quality within the catchment.*

Literature suggests that the frequency and purpose for which a household utilises water is influenced by their perceptions of the water source. Unpacking the community's knowledge of river water quality and its impact in a catchment is pertinent to understanding what informs their perceptions.

- *Forward recommendations pertaining to water quality, environmental health and land use practices.*

Understanding the links between water quality, environmental health, and land use practices are vital for management practices. Based on the findings which emanated from this study, remedial measures to address the specific challenges in managing river water quality within the catchment.

1.5. Brief summary of the methodological approach

This study adopted a case study approach using a mixed methodological design. Both primary and secondary data was collected to inform the study. Secondary data was obtained from the eThekwini Water and Sanitation Unit within the Municipality and included water quality assessments and land use maps that were used to characterise temporal variations in water quality and land use practices across the catchment. The availability of data dictated an 11-year timeframe for the above classification. The water quality and spatial data were analysed by identifying relevant parameters, representing the data in graphs and tables. The Statistical Package for Social Sciences (SPSS) software was used to highlight changes and trends between the different sample sites and years. Spatial data obtained from the Municipality included land use classes, settlements, suburbs and co-ordinates of the water testing sites. This was used to display the changes in land use over the 11 years and the spatial variability of the water quality parameters. Primary data was generated using quantitative household surveys and observational checklists that captured uses of the Umhlatuzana river. A total of 350 households were surveyed using face-to-face interviews at selected sites within the catchment to understand the communities' perception and usage of the river.

1.6. Structure of the dissertation

This dissertation is divided into five chapters. Chapter One provided an introduction for the study as well as provided the context, research questions, aim, objectives and rationale. Chapter Two provides the conceptual framework of the study as well as a detailed examination of literature relevant to the study. Chapter Three describes the methodological approach, description of the chosen study area and data sources that informed this study. Chapter Four presents the data analysis and discussion which thematically presents and discusses both primary and secondary data. Chapter Five presents a summary of the research process, recommendations and the concluding remarks.

1.7. Conclusion

The global pressures on water continue to increase as abstraction by industrial, agricultural and domestic sectors increases. Land use within a catchment impacts the quality of water. Identifying the land uses and changes over time assists in identifying long and short term stressors. The availability of water of adequate quality and quantity is declining impacting vulnerable, low-income households the most. This study identifies vulnerable households to be those within lower-income areas and households within informal settlements. It is these households which are expected to supplement piped metered water with water from the nearby Umhlatuzana River, thus, characterising these households as hybrid water users. In examining how these households utilise the river it may be possible to explore the risks posed to the health of the community as well as the ecological integrity of the river. The next chapter outlines relevant literature and how the chosen conceptual and theoretical frameworks (Geographies of Health and Socio-Hydrology) are used in this study.

CHAPTER 2
CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1. Introduction

This chapter outlines the chosen conceptual and theoretical frameworks that guided the study as well as the relevant literature. Given the complexities of this research, the frameworks, which have been adopted, include geographies of health and socio-hydrology. The geographies of health framework focus on community's experiences and perceptions of their surrounding environment and socio-hydrology, informed by socio-ecological systems, which, pays particular attention to human-water relationships. Literature includes an overview of the current water challenges and the main factors affecting land use planning in urban and peri urban landscape. This is followed by a review of water quantity and quality in South Africa, which provides motivation for the chosen water quality parameters used in this study. Lastly, a review of the various challenges that peri-urban dwellers and urban poor face in the South African context is provided, with emphasis on their access to adequate services and resources.

2.2. Conceptual framework

2.2.1. Geographies of health

Theories within geography identify that both society and space are mutually constructive (Davidson *et al.*, 2008). More specifically, places where people reside are often shaped by and in turn shape people's attitudes, identities and behaviours (Davidson *et al.*, 2008; Halpenny, 2010). Considering that health is a vital component of attitude, identity and behaviour, it can be concluded that space, and particularly place, has a part in constructing health (Davidson *et al.*, 2008). The geographies of health framework focuses on what society does to ensure conditions in which the public may be healthy (Brown and Duncan, 2002).

Medical geography was seen as a confusing sub-variety of human geography, which was primarily concerned with disease and the medical profession (Kearns and Moon, 2002). As a multi-stranded sub-discipline of geography, medical geography broadened its view to incorporate a broader range of specialist contributions (Meade *et al.*, 1988). This widened the scope of contributions and allowed for studies in cognition and perception which determined that individuals learn from their environments and the manner in which they interpret that knowledge is directly influenced by one's social and economic background (Meade *et al.*, 1988). Medical geography succeeded in bridging the gap between the biological, physical and social sciences (Meade *et al*., 1988). Kearns and Moon (2002) argue that medical geography placed unequal emphasis on the quantitative methods and only included place as a part of the critique. Although perceptions and behaviours were related to other spheres such as the economic and social, it was not adequately explored from the perspective of place. Medical geography has, however, served as a basis from which geographies of health was built (Marais and Mehlomakhulu, 2016).

Geographies of health emerged from medical geography with increased importance being placed on social models of health and place (Kearns and Andrews, 2010). Geographies of health as a sub-discipline of human geography focuses on the interaction between people and the environment in which they reside (Dummer, 2008). This framework further emphasises that the well-being of individuals is not independent of the environment in which they live, and that it is necessary to identify spatial trends of health (Kearns and Moon, 2002; Marais and Mehlomakhulu, 2016). Place is inevitably relevant for health variation as it contains both social and physical scopes, which are aspects addressed in medical geography (Cummins *et al*., 2007). Perceptions of health and pollution in the context of place, and how place affect and reflect behaviour related to health are explored more expansively within geographies of health (Kearns and Andrews, 2010). This focus on the perceptions of a community's surrounding environment assists this study by highlighting contributing factors in community behaviours and interactions with the nearby Umhlatuzana River. This is of importance since media reports show a series of pollution-related events. For example, the death of fish in the Durban Harbour in 2008 (Carnie) and *E. coli* counts of 13 000 000 per 100ml (Dawood, 2019), signalling concern over health risks.

The shift towards geographies of health provided clarity on the use of theories to understand information related to place and health (Cutchin, 2007). As a result, health inequalities, along with the forces that shaped them was viewed and investigated more critically than in previous discussions (Cutchin, 2007). This critical engagement with geographies of health has drawn on other social dimensions in the field of geography, emphasising the social and physical environments; thereby highlighting the associations between health, and the social and physical conditions of spaces (Curtis and Oven, 2012). This emphasis on placing health within the experienced reality of place has permitted research to offer more rigorous explanations for the geographical variations of health status (Brown and Duncan, 2002; Cutchin, 2007). Several studies bring to the fore the influence of water sources in urban areas on the health and wellbeing of surrounding communities (Foley and Kistemann, 2015; Gascon *et al*., 2017; Haeffner *et al*., 2017).

Health is linked to the characteristics of the place in which they reside. Moreover, there has been an increased emphasis on place and the intersection of culture and political economy in the development of place-specific landscapes of health and health care (Kearns and Moon, 2002; Atkinson *et al*., 2015). Kearns and Moon (2002) show that this shift has been a case of evolution and not revolution, as academics move from exploring health in isolation to relating it to place and other social dynamics. Geographies of health as a concept highlights the need to unpack health as not only an issue of economic power and medical well-being but also as an aspect of human life which may be directly affected by the environment in which individuals reside. Within South Africa, the historically skewed distribution of water access and infrastructure impacted predominantly poor black communities and townships (Goldin, 2010). Such a viewpoint places geography as a discipline at the forefront due to its ability to approach issues holistically. Such an approach is pertinent to this study as it aims to understand community perceptions of the Umhlatuzana River and how those perceptions influence the utilisation of the water source.

One of the main themes of geographies of health is 'place', which is seen as an operational 'living' construct that is important when studying issues of health, disease and health care (Cummins *et al.,* 2007). Various studies focus on community responses to health threats and place-specific aspects of health (Smith and Easterlow, 2005; Greene *et al*., 2014; Durkalec *et al*., 2015). As a result, health geography places increased focus on place processes rather than the ability to generalise that has led to research adopting a case study approach to investigate the phenomena (Cutchin, 2007). Understanding geographies of health can also be enhanced through the use of tools such Geographic Information Systems (GIS) to aid research by providing a mapping system that allows for the integration of different data types (Dummer, 2008; Marais and Mehlomakhulu, 2016). Likewise, this study uses multiple data types and sources to understand the interactions between land use change, water quality (physical dimension), and perceptions and use (social dimension).

The geographies of health approach often utilises a mixed methods or qualitative approach to analyse a subject matter, making use of multiple theoretical frameworks to investigate complex phenomena (Cutchin, 2007; Dummer, 2008). The mixed methodological approach combines health-related statistics with perceptions, attitudes, and experiences to inform how health may be affected by the environment (Dummer, 2008). Understanding the cognitive processes through which individuals conceptualise their surrounding environment as well as perceive risks, assists in comprehending individuals' actions and the resultant effects on that environment (Robbins, 2010). This perspective is useful for understanding decision-making processes related to the health and well-being of a community and its environment. By adopting a mixed methodology, it is possible to study the various facets related to geographies of health as it is necessary for the spatial aspects of the study and the perceptions and beliefs which influence the behaviour of the community. Also relevant to this study is the relationships that people share with the natural environment, in this case, hydrology. The details of this relationship influence perceptions, utilisation and management or protection of water sources and the associated features.

2.2.2. Socio-hydrology

Society is perceived to have the ability to alter ecological systems through land use activities and changes, and as such, this should be incorporated into studies to gain greater depth and understanding (Grimm *et al.,* 2000). Socio-hydrology is a socio-ecological system which has been described as the science of water and people. This framework seeks to apprehend the dynamics and co-evolution of human-water systems where humans and their actions are included as part of water cycle dynamics, and cannot be adequately represented independently (Sivapalan *et al*., 2012; Troy *et al*., 2015; Mount *et al*., 2016). The study of hydrology itself is highly faceted and includes fields such as contaminant hydrology, social hydrology, urban hydrology, catchment hydrology, and surface water hydrology (Lall, 2014).

Socio-hydrology attempts to bridge the gap between disciplines by incorporating socioeconomic and environmental aspects of hydrology, thus making it a science that is intricately linked to society and its needs (Lane, 2014). This approach broadens a study by focusing on the interactions, feedbacks and co-evolution of human behaviour with the hydrological system (Grimm *et al*., 2000; Elshafei *et al.*, 2014). As a discipline, socio-hydrology is considered to be relatively new integrating a historical perspective when investigating social, ecological and hydrological systems (Zlinszky and Timar, 2013). This integration has allowed for studies to investigate the co-evolution of humans and the environment, and the resultant consequences for sustainable development (Liu *et al*., 2014; Al-Amin *et al*., 2018; Xu *et al*., 2018).

Socio-hydrology is related to the hydro-social cycle, which emphasises the intrinsic link between water and people. Both include the social, political, cultural and economic systems in analyses centred on the 'water-health nexus' (Elliott, 2011; Troy *et al*., 2015). Socio-hydrology has three goals related to the social, political, cultural and economic systems (Sivapalan *et al.*, 2014):

- To analyse space-time patterns and dynamics of socio-hydrologic processes.
- Unpack outcomes related to human well-being are interpreted with regards to socio-hydrologic responses.
- To understand the importance of water culturally, economically and politically providing an explanation for the biophysical and social interactions exhibited.

The human impact on water systems combined with the need for water when forming societies has resulted in recognition of paradigms where feedback between humanity and water, water and ecological settings, and ecological settings and humanity are all bidirectional (Zlinszky and Timar, 2013). The outcome is that social and hydrologic aspects are investigated in tandem as they are created and experienced in the same world (Wescoat, 2013). Land use activities such as intensive agriculture and urban land use have a direct impact on the quantity and quality of groundwater and surrounding water bodies (Foley *et al.*, 2005). These resultant changes inevitably impact society and require management programmes that promote sustainability (Niedertscheider *et al*., 2012). These impacts may be seen as a change in water demand, altered hydrological processes, as well as a change in water quality due to surface runoff (DeFries and Eshleman, 2004). As a result, it is necessary to understand these concomitant effects from all perspectives, adopting a more holistic approach that surpasses the boundaries between disciplines for informed decision-making (DeFries and Eshleman, 2004; Zlinszky and Timar, 2013).

Among the challenges of socio-hydrology is the interconnectedness of hydrology with human behaviour in ways that are considered significant for policy and/ or economic frameworks (Lane, 2014). Historically based socio-hydrological studies are primarily quantitative due to the data available and often become qualitative when this type of data is insufficient (Zlinszky and Timar, 2013). The quantification of hydrological studies becomes increasingly difficult when coupled with human behaviour studies, which are qualitative in nature. The fusion of these two spheres of study is a complex process. The human water relationship is driven by multiple scales, decision-makers and processes and as such makes it necessary for the development of a framework, such as socio-hydrology that incorporates the aforementioned aspects (Lane, 2014). Incorporating various types of data allows for an improved understanding of the interactions occurring within the socio-hydrologic system (Mount *et al*., 2016). Due to the dynamic nature of socio-hydrology, an interdisciplinary approach using a variety of methods is required in order to examine the multi-directional inter-connections in time and space, resulting in a greater depth of analysis (Liu *et al*., 2015; Xu *et al*., 2018; Ogilvie *et al*., 2019).

The main aim of research in the socio-hydrological vulnerability frame should be to detect the spatial and temporal patterns of socio-hydrological vulnerability due to land use/cover, hydrology and socio-economic changes to obtain in-depth insight in the mechanisms of these changes (Elshafei *et al.*, 2014; Lall, 2014). This study aims to integrate people and their activities, particularly land use activities into hydrology. By integrating land use and hydrological data, it is possible to draw conclusions on the effects of social changes on water bodies (Zlinszky and Timar, 2013). Geographic Information Systems is increasingly incorporated into socio-hydrological studies resulting in improved time-series analyses thereby depicting spatial and socio-hydrologic relationships more holistically (Zlinszky and Timar, 2013).

Incorporating space and place into the study of health and viewing it from a holistic perspective warrants the use of the geographies of health as a suitable framework to unpack public health and well-being issues. Geographies of health as a framework further assists in understanding the relationship between the community and the environment in which they reside. Moreover, the framework assists this study in emphasising community perceptions of the link between their natural environment and their health. Furthermore, the framework will be complemented by the socio-hydrology framework which expands on the human and water relationship providing greater insights into community uses, vulnerabilities and perceptions of water resources. Likewise, these frameworks guide and contextualise this study, especially in catchments such as the Umhlatuzana that is characterised by diverse land uses and host a myriad of uses and users. The following section describes the relevant literature that framed this study.

2.3. Literature Review

Communities rely on natural and artificial sources of water in the surrounding catchment for domestic and industrial activities. Artificial sources of water include wells, boreholes and dams constructed to capture water for increased access and availability (Letnic *et al*., 2014). Natural sources of water such as rivers, lakes, streams and ponds depended on for domestic activities such as drinking, washing, bathing and, sanitation (Rasoloariniaina *et al*., 2014; Douglas and Isor, 2015). The use of these natural sources often varies based on the availability of piped water or access to other improved sources (Dos Santos *et al*., 2017; Elliot *et al*., 2017).

Globally, piped water from artificial sources is considered the best source for industrial, agricultural and domestic use, due to its convenience and treatment to remove biological and chemical contaminants (Tsimpo and Wodon, 2018). However, many communities still lack access to piped water and other improved sources (Burt *et al*., 2018). This is due to a myriad of factors including a lack of state or municipal capacity, lack of infrastructure, or the inability of households to pay the required tariff (Burt *et al*., 2018; Tsimpo and Wodon, 2018). As a result, many households, particularly in the developing world depend on natural sources for their basic and needs. Domestic activities such as bathing or washing of clothes and dishes, and in some cases sanitation, may be practiced close to or in the water source, making these open sources vulnerable to contamination from various sources (Rasoloariniaina *et al*., 2014; Douglas and Isor, 2015).

2.3.1. Contemporary Water challenges

Climate change poses severe threats to water availability on a global scale as it intensifies pressure on the hydrological cycle (WWAP, 2014). Regions that are arid/semi-arid will become drier and, the quantities of water available will be drastically reduced. Simultaneously, other regions that are predominantly wet will experience an increase in precipitation and become more prone to floods (WWAP, 2014). In South Africa, climate change is projected to increase air temperatures resulting in increased rates of evaporation, reducing the amount of water available (Oberholster, 2010). The eastern parts of South Africa are expected to experience an increase in summer rainfall, this raises concern since excessive precipitation after prolonged dry periods may result in floods (Faling *et al*., 2012; WWAP, 2014). Additionally, Western regions of South Africa are expected to experience decreased runoff along with an increase in annual droughts (Dallas and Rivers-Moore, 2014; Ziervogel *et al*., 2014).

Rapid population growth is one of the factors that has led to greater demand and consumption of useable water; attributed to more intense agricultural, industrial and, domestic uses (Zehnder *et al.*, 2003; Munia *et al*., 2016). Water availability is directly affected by climate change owing to greater unpredictability in rainfall patterns and a reduction, in some instances, in overall rainfall (Zimmerman *et al.*, 2008; Grouillet *et al*., 2015). This was recently evidenced by significant reductions in the Hazelmere Dam levels within the eThekwini Municipal (Ntuli, 2015). This is due to one of the most severe droughts that began in 2013 after the region received below average rains (Ntuli, 2015). In response, the eThekwini Municipality introduced water restrictions bringing into focus the importance of sustainable water use as a climate change response (eThekwini Municipality, n.d.). Furthermore, economic growth and the accompanying land use changes exacerbate pressure on freshwater resources. Water has also become a commodity which is not accessible to those without economic and political power, land rights or those who fall on the unfavourable side of socio-economic inequalities (Marshall *et al*., 2009; Munia *et al*., 2016).

Clearly, access to adequate and safe water is a multi-pronged challenge; thus, although complex, it is necessary to examine household behaviour, perceptions and interactions with their sources of water. As mentioned earlier, water quantity and quality are equally important factors to consider when addressing access to the resource. The following sections provide an overview of the main issues relating to water quantity, the factors influencing water quality and how these are assessed, and the links between water and health. These are discussed with the context of developing countries, such as South Africa.

2.3.2. Water quantity

The quantity of water delivered is equally important as the quality as an inadequate supply may prevent decent sanitation and hygiene (Hunter *et al.*, 2010). Aquifers, supply a third of the world's population, and are pumped out at a higher rate than nature can replenish thereby significantly altering flow dynamics and river health (Famiglietti, 2014). Hanjra and Qureshi (2010) show that many rivers, for example, the Yellow and Ganges Rivers, are unable to flow to the sea throughout the year due to upstream withdrawals. Less than 3% of the world's water is safe to drink or use on crops and approximately two thirds of that water is locked in glaciers, as a result only 0.01% of the water on earth is available in freshwater lakes and rivers (Jackson *et al.*, 1989; Reid *et al*., 2019). The scarcity of freshwater is ranked in the top five global risks in terms of impact on society (Dos Santos *et al*., 2017). Southern Africa is a 'critical region' of water stress primarily due to most of the water management areas in the country being in deficit (Dallas and Rivers-Moore, 2014). Poor distribution, inequitable allocation, pollution, ineffective governance, and weak political structures all contribute to water-related challenges in Sub-Saharan Africa (Dos Santos *et al*., 2017; Pahl-Wostl *et al*., 2013). These issues plague both urban and rural contexts.

Compounding these issues are the skewed rainfall patterns experienced in the country. Rainfall in South Africa varies greatly from the West to the East coast of the country (Zucchini and Nenadic, 2006). The Mean Annual Precipitation (MAP) differs significantly with the interior and western region receiving less than 500 mm, the eastern region receiving between 500 mm and 1 000 mm and south eastern coastline receiving between 1 000 mm to 2 000 mm of rain (Dallas and Rivers-Moore, 2014). Freshwater is becoming more difficult to access in the more arid regions of the country (Adewumi et al., 2010). Water availability is also skewed towards the urban centres as some of the cities have water supplies comparable to cities in developed countries (Dallas and Rivers-Moore, 2014). For other villages, towns, and rural and peri-urban areas, the supply of potable water may be erratic and result in local communities using freshwater sources to services all or some of their domestic needs (Edokpayi *et al*., 2014).

South Africa is a naturally water-scarce country with the majority of the available water being utilised by the agricultural sector (60%), followed by the domestic (27%) and power (4%) sectors, while the remaining 9% is used by the industrial and mining sectors, amongst others (Department of Water Affairs [DWA], 2014). The drought brought on by El Niño in 2015 and 2016 resulted in five of the nine provinces in South Africa being declared disaster zones, including KZN (Ntuli, 2015). During this drought the eThekwini Municipality, which is the largest local municipality in KZN, reduced water pressure to households in an attempt to reduce withdrawals from declining dam levels and, imposed fines on those who exceeded the permissible limits (Stolley, 2015). This and the resultant water shortages highlight the importance of ensuring that all freshwater systems, independent of size, remain healthy and viable for both social and environmental benefits.

2.3.3. Water quality and related parameters

As a global concern, water pollution has detrimental effects on both environmental and human health (Khan *et al.*, 2013). The pollution of water has been linked to urbanisation and industrialisation since the 1990s (Khan *et al.*, 2013). Both surface and groundwater may become contaminated due to surface runoff through urban areas, pastures, leakage of raw sewerage from septic tanks and, sewerage disposal systems (spillage from poor practices and outdated infrastructure) (Azizullah *et al.*, 2011). Besides pathogenic microorganisms, chemical impurities are of equal importance when discussing water quality as many developing countries are experiencing rapid industrialisation (Zhang, 2012). Contamination may result from the disposal of industrial and municipal waste directly into surface water sources without being adequately treated (Azizullah *et al.*, 2011).

Water quality and water quantity are inextricably linked to sanitation since water pollution and related illnesses, at global and local scales, are often reported as consequences of poor management of sewage and human waste (Moe, 2006; Baba, 2017; Pal *et al*., 2018). Potable water that has been contaminated with faecal matter increases the transmission of waterborne diseases and compromises public health (Zhang, 2012; Khan *et al*., 2013). Water of poor quality contains pathogens and chemicals which when ingested results in gastrointestinal diseases that have become a major cause of death worldwide, particularly in developing nations where many communities lack access to safe drinking water (Ishii and Sadowsky, 2008; Baba, 2017). The quality of water in a water body may be degraded due to various factors such as land use activities of rural and urban areas. Rural land use is usually associated with agriculture and may influence the amount of soil and nitrates in a water body, while urban areas are known to contribute more chemical properties (Seeboonruang, 2012). Peri-urban areas are characterised by their mixture of land use and may contain both urban and rural land use activities. There may also be an increase in informal dwellings which lack adequate access to water and sanitation, therefore increasing the likelihood of soil and surface water contamination water (Parkinson and Tayler, 2003; Fitchett, 2017).

This study utilises the WHO water quality guidelines on water quality aimed at protecting public health and evaluating the suitability of water (WHO, 2011). Additionally, understandings of water suitability are examined using guidelines established by the Department of Water Affairs and Forestry (DWAF), specifically the South African Water Quality Guidelines for Domestic Use (SAWQG-DU) and the South African Water Quality

Guidelines for Recreational Use (SAWQG-RU). These guidelines are pertinent to municipalities testing water samples to adhere to the national standard. Both physical and biological parameters were considered when selecting variables to determine the water quality of the Umhlatuzana River. Biological indicators *E. coli* and *T. coli*, encompass a wide range of bacteria and as such indicate the hygienic qualities of water and has a direct influence on the health risks. Physico-chemical variables include turbidity, Dissolved Oxygen (DO), pH, Total Dissolved Solids (TDS), and Electrical Conductivity (EC). Although some physico-chemical variables such as DO and pH do not have a direct impact on human health, it is an appropriate indicator of water quality, and have been included in this study. The following sections provide a brief description of the chosen variables and how they were used in this study.

2.3.3.1. Turbidity

Turbidity refers to suspended or colloidal matter present in water, which interrupts the light scattering ability (DWAF, 1996a; Yang *et al.*, 2015). Turbidity can be commonly associated with the degree of clarity or the transparency of water and is associated with water colour. Turbidity influences river health as high levels of turbidity reduce plant growth due to limited sunlight penetrating the water, thereby reducing the production of oxygen by riparian flora (Henley *et al*., 2000). Turbid water is often perceived to be of poor quality and is associated with pollutants by the consumer (WHO, 2011). Although turbidity is not in itself a health threat, the presence of particulate matter is linked with microbial contamination, parasites and other contaminants that attach themselves to these particles (Yang *et al.*, 2015). The unit of measure for turbidity in this study is Nephelometric Turbidity Units (NTU), and water samples were tested with a nephelometric turbidimeter on the day of collection (DWAF, 1996a and WHO, 2011).

It has been established by the WHO that turbidity levels are to remain below 5.0 NTU to avoid adverse health effects (WHO, 2011; Yang *et al.*, 2015). The South African guidelines for domestic water usage stipulate that turbidity levels may not exceed 1 NTU and the guidelines for recreational water utilisation recommends that turbidity levels not exceed 5 NTU. It is necessary to note that these limits are far below the range often found in South African rivers (DWAF, 1996b). Although turbidity does not affect health directly, it is often associated with outbreaks of microbiological contamination and is used as a general indicator of drinkability (Mann *et al*., 2007; de Roos *et al*., 2017). Turbidity has been shown to have a negative effect on the survivability of organisms, affecting feeding, growth and reproduction of aquatic species (Carrasco *et al*., 2013).

2.3.3.2. EC/ TDS

Dissolved ionised solids are a natural component of water and is measured by the ability to conduct an electrical current (Jackson *et al*., 1989; Berger *et al*., 2017). The conductivity level of water indicates salinity levels which can impact river and consumer health (DWAF, 1996a). Drinking water with high conductivity levels is likely to cause hypertension, kidney failure, and stone deposition in various parts of the intestine if consumed regularly (Rahman *et al*., 2016). Units of measure for EC are millisiemens per metre (mSm/m) (Jackson *et al.,* 1989). The conductivity of most natural waters is converted to TDS concentration by a conversion factor that ranges between 5.5 and 7.5, with the average conversion factor taken as 6.5 (DWAF, 1996a). This equation was used to convert electrical conductivity results into TDS in order to assess its possible impacts on human health and the ecology of the river.

Total Dissolved Solids is composed of inorganic salts such as bicarbonate, chloride, calcium, magnesium, potassium, and sodium (Rahman *et al*., 2016). According to DWAF (1996a), the target range for TDS ranges between 0 and 450 mg/l where it may have a flat bland taste but no effects on health. For concentrations 1 000 mg/l and higher, the water will develop an unpleasant taste (WHO, 2011). Moreover, TDS measuring between 450 and 2 000 mg/l has a much more noticeable salty taste and may increase scaling and corrosion on plumbing but is still unlikely to have an adverse effect on health (DWAF, 1996a; Mohsin *et al.*, 2013). At 2 000 mg/l and higher, the taste becomes increasingly salty and bitter and may result in a disturbance of the bodies salt balance (DWAF 1996a).

Salinity levels of freshwater is noted to be between 0 and 1 000 mg/L, and increasing salinity in freshwater is a serious environmental challenge due to the effects on river ecology and biodiversity, impacting mortality and reproductive rates of salt sensitive taxa (James *et al*., 2003; Kefford *et al*., 2004; Sharma, 2008; Jeppesen *et al*., 2015). Additionally, increases in Biological and Chemical Oxygen Demand (BOD and COD, respectively) occur when there are high levels of dissolved solids in a water system, resulting in the depletion of dissolved oxygen in aquatic systems (Jonnalagadda and Mhere, 2001). Increased levels of EC and TDS have been noted above guideline limits in the Palmiet and Sezela rivers in eThekwini (Chetty and Pillay, 2019).

2.3.3.3. pH

The potential of hydrogen (pH) is a scale which is used to measure alkalinity and acidity in soluble water bodies, with levels greater than 7 considered to be alkaline while a pH level below 7 is considered acidic (DWAF, 1996a; WHO, 2011). Ecologically, a high pH level may increase the alkalinity of a river, altering the toxicity of other pollutants found in the river, while low pH levels affect the toxicity level of the river as it increases the solubility of other elements such as copper and iron (Morrison *et al.*, 2001). Land uses such as urbanisation may increase alkalinity of urban waters due to the weathering of impermeable surfaces such as cement (Kaushal *et al*., 2013).

The pH does not affect human health directly, however at extremes, the solubisation of toxic heavy metals and other ions have an adverse impact on the health of people who consume this water (DWAF, 1996a; Radfard *et al*., 2019). It is difficult to identify a direct relationship between pH levels and health as pH is closely related to other water quality parameters (DWAF, 1996a). Furthermore, a pH that is too high would taste sour and a pH that is too low would taste soapy or bitter (WHO, 2011; DWAF, 1996a). The ideal pH level for drinking water is between 6.5 and 8.5, and at this level there are no noteworthy effects on taste or appearance and metal ions are less likely to dissolve (DWAF, 1996a; WHO, 2011). A study by Moodley *et al.* (2015) revealed that pH levels outside the range for freshwater at sites associated with industrial effluent/activity. Other studies have also indicated that pH is an important parameter to include in water quality studies and may remain with guideline limitations (Madikizela and Chimuka, 2017; Chetty and Pillay, 2019).

2.3.3.4. E. coli

Escherichia coli is the most accurate indicator of faecal pollution (Edberg *et al.*, 2000; Baba, 2017; Messner *et al.*, 2017). Studies show that *E. coli* originates from the intestinal tract of warm-blooded animals (including humans) and is generally harmless within intestinal organs (DWAF, 1996a; Edberg *et al.*, 2000; Xue *et al*., 2018). However, when ingested and found in other parts of the body, it is likely to cause urinary tract infections and meningitis (WHO, 2011). Drinking water polluted by *E. coli*, likely to be contaminated by sewerage, increases the risks of microbial infections and is linked to diseases such as gastroenteritis, cholera and typhoid fever, which can be fatal if not treated (DWAF, 1996a; Matano *et al.*, 2013). Moreover, events of *E. coli* contamination have been linked to raw produce as seen in the state of New Mexico, United States of America (USA), where fresh bagged spinach resulted in several people being hospitalised, as well as in Nigeria where tomatoes were contaminated (Shenge *et al*., 2015; Sharapov, 2016). As a result, *E. coli* is a significant indicator considered when investigating water quality and health (Ishii and Sadowsky, 2008).

In the South African context, water samples collected by local municipalities are tested for *E. coli* using the filtration method, passing the diluted solution through a membrane (Chiang *et al*., 2014). For this purpose, 10 ml of the original sample is diluted into 90 ml of sterilised deionised water. This 100-ml solution is filtered through a membrane, with the resultant colonies after incubation counted. The total number of bacteria can be calculated according to the number of colonies which are formed and is recorded in Coli Forming Units per 100 ml (Chiang *et al*., 2014). The prescribed level of *E. coli* in water for domestic use is 0 and for recreational activity is 130 CFU according to the SAWQG-DU (DWAF 1996a). Studies on river water in eThekwini which include *E. coli* have reported levels that exceed the guideline limitations (Baker *et al*., 2015; Sibanda *et al*., 2015).

2.3.3.5. T. coli

Total coliforms is often used to measure the hygienic qualities of water, and encompasses a wide range of bacteria (DWAF, 1996; Divya and Solomon, 2016). Although *T. coli* are not a direct indicator of faecal contamination as it also includes organisms that can live and grow in water (WHO, 2011). The *T. coli* is found in both sewage and natural water and are excreted by both humans and animals and is measured as the number of colonies found per 100 millilitres of water (DWAF, 1996a; WHO, 2011). Similar to *E. coli*, *T. coli* may be analysed by membrane filtration, pour plates or multiple tube fermentation. The eThekwini Municipality measures *T. coli* with the use of the membrane filtration method, counting the consequent colonies that had formed on the membrane (Chiang *et al*., 2014).

The presence of *T. coli* in water indicates that there has been inadequate treatment of the water or the presence of microbial growth in the distribution system (WHO, 2011; DWAF, 1996a). As noted above, *T. coli* includes bacteria not of faecal origin as well as bacteria of faecal origin such as, *Escherichia*, *Serratia*, *Klebsiella* and *Enterobacter*, and is associated with diseases such as cholera, typhoid fever, gastroenteritis and salmonellosis (DWAF, 1996a; WHO, 2011; Molina *et al*., 2015). These are diseases that if left untreated may result in death. As a result, *T. coli* is a significant parameter to include when analysing water quality. The preferable range of *T. coli* after testing is between zero and 5 counts per 100 ml (0 to 0.005 counts/L) (DWAF, 1996a). Results above 100 counts/100ml or 0.1 counts/L indicate that there is a definite growth of colonies within the water, which pose a health risk of contracting infectious disease if used for any domestic purposes (DWAF, 1996a).

2.3.3.6. DO

Dissolved Oxygen is the amount of oxygen that is present in a water sample and is considered a reliable water quality indicator (McEvoy, 1996). The DO is reduced when organic matter is discharged into the water body because aerobic microorganisms require oxygen during metabolic degradation of organic matter (Ibanez *et al.,* 2007). Dissolved Oxygen is required for the survival of aerobic organisms in the water and as such, any depletion of oxygen may alter the ecology of the river, resulting in the death of many organisms, particularly fish (Jackson *et al.*, 1989; Ibanez *et al*., 2007).

Moreover, DO is vital for the purpose of aerobic treatment processes which assists in purifying domestic and industrial wastewater (Sener *et al*., 2017). Most species of fish require a DO concentration of 5 mg/L and although it does not have a direct impact on human health, it is being used as an indicator of environmental health for this study (McEvoy *et al.,* 1996; Sener *et al*., 2017). Although DO is not an indicator of suitability for human utilisation, it is an indication of river and ecological health. In this study DO is used to show overall health of the river system and speaks to the resultant environmental impacts associated with land use change and domestic uses. Levels of DO can be affected by WWTW as the aeration process increases the DO levels in the final effluent as noted downstream from the Amanzimtoti WWTW (Madikizela and Chimuka, 2017). In this study, river health is examined using the composite river water quality index, as discussed below.

2.3.3.7. River Water Quality Index (RWQI)

Indices for measuring water and specifically river water quality is an established approach that is not unique to eThekwini. The RWQI is a scale created by the eThekwini Municipality to measure the water quality of rivers that flow within the Municipal boundaries. The scale is from 1 to 4 with 1 representing ideal and 4 representing water quality in critical condition. The RWQI is based on *E. coli* and PV4 (potassium value measured after 4 hours, which can be used as an indicator of organic load) levels measured from each water sample. Rivers that are categorised as being critical for 65% of the year are prioritised in environmental management initiatives. The eThekwini Municipality may be considered reactive as opposed to proactive with regards to monitoring and evaluation of fresh water sources since actions is only taken once an event occurs, even though samples are collected throughout the year. Although not a national scale for determining water quality, the RWQI provides insight on the desired levels for acceptable water quality at the local level.

Water quality is inextricably linked to its surrounding environment and is influenced by the type of land use activities within the catchment. Therefore, this study sought it necessary to investigate the types of land use that occur within the catchment. Land use activities are determined by anthropogenic actions, moulding the landscape according to human needs. These activities not only influence biodiversity levels in natural landscapes but also the quality of surface water.

2.3.4. Land use activities and impacts

Water quality is inextricably linked to the surrounding natural and built environments. The type of land use activities within the catchment can influence many of the water quality parameters mentioned above due to the discharge of untreated wastewater, pollutants from surface runoff and the dumping of domestic waste and greywater (Kulabako *et al*., 2009). Therefore, it is necessary to investigate the types of land use that occur within the catchment in an attempt to better understand the fluctuations in water quality. Anthropogenic activities such as converting land to suit human needs and changing land use management practices have resulted in the drastic alteration of natural landscapes (Foley *et al.*, 2005; Inostroza, *et al*., 2016). Some land use activities such as farming practices and urbanisation have changed the Earth's land surface and are linked to the decline of biodiversity and soil and water degradation (Foley *et al.*, 2005; Minta *et al*., 2018). By analysing the changes in land use and land cover it is possible to assess changes at various spatial scales as well (Marsh *et al*., 2017). The analysis of land use changes has evolved, and the use of GIS and remote sensing have significantly enhanced monitoring over improved temporal and spatial scales (Mohamed, 2017). This also allows for more integrated approaches that combine both spatial and ecological assessments (Shi *et al.,* 2010; Jeevalakshmi *et al*., 2017).

Different land use practices impact water quality in different ways. For example, agricultural activities may result in surface runoff containing excess nutrients such nitrogen, increasing the eutrophication of these waters (Nyenje *et al*., 2010). Industrial land uses have a number of effects on water quality due to the different industrial processes. Industrial discharge may include brine and sewage sludge, chemicals such as chlorine, heat pollution and heavy metals such as lead and chromium (Oelofse, 2010; Rajaram and Das, 2007). Surface runoff from urban and peri-urban landscapes also consists of different pollutants; for example, residue from small-scale farming (Allen *et al.*, 2006a). The urban and peri-urban poor lack access to basic services such as water and sanitation and therefore rely nearby water sources. This reliance exacerbates pressure on these systems and compromises their heath due to increased pollution associated with dumping of grey water and various types of human waste (Allen *et al.*, 2006a; Marshall *et al.*, 2009).

Land use change includes the clearance of natural vegetation in order to make way for agricultural activities or the construction of infrastructure and urban settlements. This clearance is common in most developing countries such as South Africa, concomitantly affecting the functioning of natural ecosystems and increasing siltation of rivers (Goble *et al*., 2014; Mangwale *et al*., 2017). The excessive clearing of vegetation results in a loss of biodiversity and negatively impacts ecosystem services such as carbon sequestration and water quality control (Gibbons *et al*., 2008; Reside *et al*., 2017). Moreover, a reduction or clearance of natural vegetation results in greater erosion of topsoil and increased surface runoff contributing to high levels of turbidity and sedimentation in water sources (Volante *et al*., 2012).

Agricultural land use activities dominate anthropogenic practices within the developing world and consume the majority of available freshwater (Pfister *et al.*, 2011). A combination of intensive agricultural practices and the use of pesticides result in accumulation of these pesticides in surface run-off thereby increasing environmental contamination (Lundqvist *et al*., 2019). Fertilisers in surface runoff enter surface water bodies, contributing to the eutrophication of surface waters and thereby reducing oxygen levels (Galbraith and Burns, 2007; Dabrowska *et al.*, 2017). Within KZN, there is extensive sugar cane farming which increases the rate of soil erosion due to the extensive periods of soils remaining bare contributing to the transportation of sediment into nearby aquatic systems (Martinelli and Filoso, 2008). As one of the largest sugar cane producers in the world, this crop contributes greatly to South Africa's economy, with the majority of activities occurring in KZN (Baiyegunhi and Arnold, 2011). The resultant effects of sugar cane cultivation on the surrounding environment includes increased soil erosion, sedimentation, and the runoff of fertilisers, herbicides and pesticides (Martinelli and Filoso, 2008; Hess *et al*., 2016).

Soil erosion increase sediment loads deposited into riparian habitats resulting in the increase in turbidity levels as well as the deterioration of these ecosystems. Catchments dominated by sugar cane farming (such as the Komati-Lomati and Crocodile River catchments) have experienced an increase in the concentration of nutrients in surface water bodies (van der Laan *et al*., 2012). Similarly, Rolfe and Harvey (2017) show that increased nutrients and other agricultural chemicals have been linked to the deterioration of the Great Barrier Reef due to surface runoff from nearby farming along the coast.

Urban sprawl is one of the main forces transforming landscapes, increasing the pressures on surrounding water resources and natural ecosystems thereby contributing to ecosystem loss (Grimm *et al*., 2000; Paul and Tonts, 2005). The prominence of impervious surfaces intensifies runoff whilst the diversity of activities occurring in urban regions, such as use of domestic chemicals, backyard mechanics and urban gardening, result in a myriad of pollutants entering water bodies (Malmqvist and Rundle, 2002; Baek *et al*., 2015). Within the urban environment the collection of urban wastewaters is one of the most pertinent hydrologic infrastructures (Ana and Bauwens, 2010; Windsor *et al*., 2019). Waste Water Treatment Works (WWTW) often release treated waters into nearby water bodies (Sauer *et al*., 2011). Poor performance and malfunctioning of WWTWs coupled with increased pressures of urban expansion and surface runoff often result in devastating impacts on water bodies within an urban setting (Sanchez-Avila *et al*., 2009; Sauer *et al*., 2011; Windsor *et al*., 2019). Expanding urban centres also increase demand for energy, food and water, compounding pressures on water resources (Redman and Jones, 2005). The expansion of urban centres through construction activities are major contributors to air, water and noise pollution, further contributing to sanitary waste, dust and particulate matter found in surface runoff (Shen and Tam, 2002; Celik *et al*., 2017). Studies show a clear relationship between land use changes and water quality particularly in urban centres (Ren *et al*., 2003; Haidary *et al*., 2013; Pullanikkatil, 2015).

Transformations of the urban landscape are multidimensional, highly dynamic and non-linear (Banzhaf *et al*., 2017). The emergence and rapid expansion of megacities and urban landscapes in developing countries further exacerbate pressures on fresh water bodies (Choi and Wang, 2017). Coupled with this extensive growth, the rate at which megacities are able to build infrastructure and provide services is dwarfed by the rate of population growth (Moe, 2006; Owusu, 2010). Many developing countries have attempted to keep pace with the rapid rate of urbanisation through formal land development programmes such as public housing provision

(Kombe, 2005; Cobbinah *et al*., 2015). However, developing countries have been unable to keep up with the rate of urbanisation and are therefore unable to sufficiently respond to the needs of the poor (Kombe, 2005; Zhang, 2016). This has resulted in the rapid growth of informal settlements in countries like South Africa that introduce a myriad of social and environmental concerns (Kovacic *et al*., 2016). By definition, informal settlements are considered to be residential areas situated on land, which has been occupied illegally, and do not comply with any building or planning regulations, do not grow on a linear pattern but instead explode at a certain growth period (Okurut *et al*., 2014; Stone and Howell, 2019).

Households in newer informal settlements lack safe and secure shelter and basic services such as adequate sanitation, drainage and removal of waste, resulting in unhealthy environmental conditions (Kombe, 2005; Kulabako *et al.*, 2010). Historical informal settlements established in the 1970s and 1980s apartheid era, often after mass evictions, have campaigned for access to basic service delivery such as water, electricity and sanitation (Weiss, 2014). It has been observed that many vulnerable households settle on marginalised land without formal property rights, which limits access to adequate basic services to support their needs, such as sewer lines and water mains (Marshall *et al*., 2009; Okurut *et al.*, 2014). As a result, without sufficient access to water mains and sanitation, households are likely to supplement their domestic needs by using nearby natural sources such as rivers. In this regard, these communities are more susceptible to environmental changes such as the decline of water quality of nearby sources (Gallopian, 2006).

Peri-urban settlements are areas with relatively flexible boundaries situated on the fringe of a city and is one of the more viable strategies when the vulnerable poor intend to begin a livelihood in an urban area (Kombe, 2005; Allen *et al.*, 2006b; Hatcher *et al*., 2019). These areas are constantly undergoing change and are rarely spatially zoned and comprise of a mixture of urban-rural interactions as it is the boundary between the rural and urban worlds (Sadiki and Ramutsindela, 2002; Thornton, 2008; Marshall *et al*., 2009; Lombard, 2016). Within the South African context, it is necessary to note that the development of peri-urban fringes is due to the legacy of apartheid segregation. This resulted in the migration of black individuals into previously white areas, particularly in KZN (Sadiki and Ramutsindela, 2002).

Peri-urban areas can be characterised by the lack of access to services, resulting in the majority of the peri-urban poor having a greater dependence on their natural environment (Marshall *et* *al*., 2009; Lombard, 2016). Without proper planning peri-urban households may be without basic services such as piped sanitation and instead rely on Septic Tank Systems (STS) (Withers *et al*., 2013). Without regular maintenance, older systems may be placed under increased pressure from expanding communities and, the dilution abilities of the river within the upper catchment may decline (Withers *et al*., 2011; Withers *et al*., 2013). The leaking or failure of STS would contaminate nearby water sources, leading to eutrophication, disease outbreaks and increasing faecal coliform levels (Withers *et al*., 2013). The concomitant impacts of limited service provision result in the accumulation and poor disposal practices of wastes that contaminate local environments and subsequently water bodies (Kombe, 2010; Mirosa and Harris, 2011). Assessing the interactions between people and water should involve an appreciation of the legislation that governs peoples' access to water, as well as the attitudes and perceptions of consumers.

2.3.5. Policy agendas and water access

It has been noted that access to water is shaped by policy agendas within the South African context, resulting in these policies playing a guiding role in determining and influencing community access to water. During the apartheid regime, government policies were designed for servicing the needs of the white minority as well as supporting sectors that improved the country's economy (Abrahams *et al.*, 2011; Das-Munshi *et al*., 2016). The public service system was politicised and used a tool for oppression resulting in the black majority, which was the country's poor, living on water scarce land and lacking access to adequate sanitation and water services (Tshandu and Kariuki, 2010; Abrahams *et al.*, 2011).

Before the end of apartheid, South Africa had become one of many countries which adopted neoliberal policies (Mirosa and Harris, 2011). Neoliberalism became increasingly prominent within government initiatives such as the 1994 Reconstruction and Development Programme (RDP) and the 1996 Growth, Employment and Redistribution framework (GEAR); a Macroeconomic Strategy for South Africa (William and Taylor, 2000; Karriem and Hoskins, 2016). Post 1994, the National Government was tasked with addressing the resultant effects of Apartheid as well as incorporating South Africa into the global environment (Tshandu and Kariuki, 2010). The RDP was created after the 1994 elections and aimed to meet basic needs of citizens through job creation, provision of housing, health, electricity, water services and, infrastructure (Mirosa and Harris, 2011). The RDP was however abandoned in 1996 in favour of the GEAR framework which prioritised economic growth, an open economy and privatisation of social services (Mirosa and Harris, 2011; Karriem and Hoskins, 2016). The GEAR plan made development priorities such as the provision of social services subject to cost recovery and fiscal discipline, limiting the ability of the government to advance the rights of historically marginalised groups (Tshandu and Kariuki, 2010; Black and de Matos-Ala, 2016). In South Africa there has been a strong decentralisation of power and functions to local government, this has increased the responsibility of local cities/ municipalities in order to address the challenges of rapid urbanisation and its associated challenges such as service delivery (Cameron, 2014). In response to service delivery challenges, South African provinces and municipalities have adopted alternate methods of public service delivery such as making use of public-private partnerships (PPPs) (Naidoo and Kuye, 2005; Ruiters and Matji, 2016). The use of PPPs is an attempt to improve the efficiency of services and ensure its cost effectiveness (Naidoo and Kuye, 2005; Ruiters and Matji, 2016). The decentralisation of water provision to municipalities and PPPs has resulted in a patchwork of water governance, provision and institutions in South Africa (Mirosa and Harris, 2011).

In the eThekwini Municipality, the Water and Sanitation Unit acts as the designated Water Services Authority and has been seen as a pioneer in sustainable water services (Hellberg, 2014; Sutherland *et al*., 2015). Although previously praised for good leadership and highly capacitated and motivated staff, several staff members of the Water and Sanitation Unit and service providers are part of an ongoing investigation into alleged fraud, corruption and money laundering (Sutherland *et al*., 2015; South African Police Services, 2020). Perceived and actual public sector corruption erodes the publics' trust in public officials, units and departments, impacting their attitudes, actions and willingness to participate (Pillay, 2017). These aspects of fraud and corruption also impact the provision of basic services. The persistent fraud and corruption within all levels of government are evidenced in the perpetual backlogs experienced in the extension of basic services to the South African populace, particularly the poor.

Privatisation has in some cases been proven successful at addressing challenges such as nonrevenue water, increased revenue collection and the expansion of network services which has been an attractive policy option for governments facing physical water scarcity and fiscal austerity (Pierce, 2012). The privatisation of water and the commodification of water management has been an example of the neoliberalisation of resources (Mirosa and Harris, 2011). Neoliberalism endeavoured to meet both economic and environmental ends through the private sector (Bakker, 2005). The private sector has been criticised for the poor servicing of poorer households and neoliberalism has been seen as promoting the appropriation of the natural environmental for profit (Bakker, 2013). Pre-paid metering of low-income households has resulted in them paying more for water than higher income households as they not only pay for water usage but for the water meter as well (Mathekganye *et al*., 2019). Additionally, households fear disconnection, debt collectors and imposed droughts should they be able to pay for water used (Hellberg, 2014). This privatisation of resources through metering of water limits lower income households from affording access to sufficient metered water, resulting in households supplementing their needs with water from communal standpipes or nearby inferior sources such as dams or rivers.

2.3.6. Water legislation in South Africa

Water is considered a basic human right, as such fresh water is a legal entitlement, and not a service provided on an altruistic basis (Allen *et al.*, 2006b; Rodina, 2016). Although considered a basic human right, the introduction of water tariffs and the privatisation of water services are strategies employed to recover costs as governments are unable to ensure access to water for many of their citizens (Allen *et al.*, 2006b; Ruiters and Matji, 2016). The inclusion of the private sector in the provision of drinking water is a highly contested strategy; although it is believed to improve efficiency, it may not be accessible to those who cannot afford the service (Kosec, 2014).

The South African Constitution and several by-laws attempt to redress injustices of the past and cement the right to water for all whilst emphasising the need for effective management of national resources. The principal legislation governing water includes the Constitution of the Republic of South Africa Act 108 of 1996, National Water Act no 36 of 1998 and the Water Services Act 108 of 1997 (Algotsson *et al*., 2009). Section 24 of the Constitution pertains to the environment and indicates that everyone has a right to an environment that is not harmful to their health and well-being (Republic of South Africa, 1996). Additionally, Section 27b specifies that everyone has the right to access sufficient food and water (Republic of South Africa, 1996). Together, these sections advocate for the fair distribution of clean water, however without enforcement, many South Africans are exposed to polluted environments and lack sufficient access to a basic human right.

The National Water Act No. 36 of 1998 stipulates that the protection, use, development, conservation, management and control of South Africa’s water sources should be done in a sustainable and equitable manner, for the benefit of all persons. The Act also gives effect and support to the role of the local government municipality in service delivery, including clean water supply (Abrahams *et al.*, 2011). This hereby devolves responsibility of the provision of water from the National government to local municipalities. The main aim of the Water Services Act 108 of 1997 is to provide for the right of access to basic water supply and basic sanitation. Additionally, the setting of national norms and standards for water service tariffs assists in securing sufficient water availability and ensuring an environment that is not harmful to human health (Republic of South Africa, 1997). The Act also provides a regulatory framework for water services institutions and water services, promoting the effective management and conservation of water resources (Republic of South Africa, 1997).

Additionally, the Free Basic Services Policy, announced by government in 2000, has made provision of 25 L per person per day of safe water, which amounts to 6 kilolitres per month per household (Abrahams *et al.*, 2011). This is greater than the 20 L prescribed by the WHO and UNICEF Joint Monitoring Programme assuring individuals have sufficient water for all domestic and consumption needs (Howard, 2003). Moreover, the Strategic Framework for Water Services established in 2003, was developed to take into account the progress in the establishment of democratic Local Government, addressing the full spectrum of water supply and sanitation services together with the relevant institutions (Abrahams *et al.*, 2011).

South Africa has drafted and enacted several by-laws, regulations and policies that speak to the quality, management and provision of water in the country. Legislation in relation to the provision of water is difficult for local municipalities to uphold, due to financial and capacity related challenges. Similarly, the enforcement of water protective laws is criticised as being poor, this has been attributed to a lack of political power as well as a lack of capacity (Musingafi *et al*., 2013; Stacey, 2018). In order to improve the state of water in the country and the effectiveness of related laws, regulations and policies, it is suggested that the different spheres of government coordinate efforts and cooperate with one another (Stacey, 2018). Additionally, data on the status of South Africa's waters is vital and must be analysed so as to draft an appropriate management strategy for the country (Muller *et al*., 2018). The nature of interaction between people and natural water sources is not only impacted by legislation but also by their perceptions and attitudes to that source. These perceptions and attitudes are dependent on personal opinions and previous experiences and is pertinent to understanding the human-water interaction. These aspects rarely feature in water-related policies and legislature.

2.3.7. Perceptions and attitudes of water resources

The use and perception of a water source differs across and within communities (Dogaru *et al.*, 2009). The perceptions of water attributes are often based on the waters source and vary among individual's socio-economic status, as well as among regions and countries (Hurlimann and Dolnicar, 2016). One of modern society's characteristics is a high and general concern for the environment, highlighting the levels of awareness regarding the impacts of human activities on the natural environment (Berenguer *et al*., 2005). Environmental concerns, such as degradation and climate change are based on the attitude and perceptions of the individual. A theoretical perspective that explains the basis for environmental concerns is the "objective problems- subjective values" explanation (Bi *et al*., 2010, Echavarren, 2017). Inglehart (1995) argues that countries and communities with objective environmental issues are more likely to support environmental protection activities. Furthermore, subjective cultural factors note that affluent countries and communities are usually comprised of individuals with Post- materialist values who give a higher priority to the environment than materialist individuals do (Inglehart, 1995). Moreover, lower income communities who lack access to amenities such as piped water are often more likely to perceive changes in resources with which they have direct contact and which they depend on, such as water (Dlamini *et al*., 2020). These lower income communities due to size and density may also be located in less desirable areas, which are in proximity of pollution and environmental degradation (Inglehart, 1995). As a result, it is expected that lower income communities who are in direct contact with environmental services are more likely to perceive degradation of the resource.

An individual's perception of an environmental issue is affected by various socio-economic factors, including employment status, education, age, gender, place and length of stay in the affected community (Dogaru *et al*., 2009). Dlamini *et al.* (2020) noted that in a South African setting, education level (up to matric), employment status and dwelling type was significantly associated with environmental perceptions. Although materialistic in nature, Dixon and Durrheim (2004) indicate that in South Africa these factors are linked to geographical location due to separate development, past policies and the social engineering of Apartheid. Literature has shown that there are differences when investigating perceptions of environmental problems and environmental behaviours across socio-demographics such as gender, religion and age (Bi *et al*., 2010; Liu *et al*., 2014; Xiao and McCright, 2014). Place is particularly of importance as it is not only an area in which the world is experienced, but also shapes attitudes and perceptions of environmental quality (Armstrong and Stedman, 2019).

In addition, spatial proximity affects an individual's perception of the environment, particularly when concerning pollution. This is as perceived levels of pollution and quality of water sources, are based on olfactory and visual evidence (Dogaru *et al*., 2009; Faulkner *et al*., 2001). The presence of piped water has placed a filter between communities and their water source, reducing interaction to the opening of a tap (Alessa *et al*., 2007). This separation distances and desensitises consumers from the natural resource, creating a cognitive barrier which diminishing awareness of the resource and skews perceptions of its current state (Alessa *et al*., 2007). The difference between the perceived and actual state of water resources cannot differ too greatly, as this would result in serious ramifications (Alessa *et al*., 2008). These perceptions are critical in order to understand the human-environment interactions since it influences behaviour, choices and ultimately practices (Bi *et al*., 2010). Studies on perception may increase awareness in affected communities as well as aid in decision-making, by understanding the opinions of the community when creating policies (Dogaru *et al*., 2009; Sulemana *et al*., 2016).

The perceptions of communities in South Africa today are impacted by the legacy of Apartheid. Historically, the black majority of South Africa were denied access to land, education, basic services and, natural resources because the government only provided infrastructure to previously advantaged households (Vemerink *et al*., 2011; Movik, 2014). Many of the water related laws were made under the guise of conservation, distorting the perception and attitudes of the impacted black population (Templehoff, 2017). Although laws created post 1994 have attempted to address the past injustices, the free-market capitalist system has promoted the prioritisation of the private sector above the public sector (Rawlins, 2019). As a result, the development and access to infrastructure and resources are geared toward the wealthy, increasing tensions, and negative attitude toward conservation (Vemerink *et al*., 2011; Rawlins, 2019). Additionally, poverty-stricken or disadvantaged communities are more likely to rate socioeconomic issues such as poor health care or hunger as more pressing issues in their community in comparison to environmental issues such as pollution or deforestation (Anderson et al., 2007).

2.4. Conclusion

The conceptual framework of geographies of health and socio-hydrology guided the selection of appropriate literature for the study. The literature reviewed within this chapter was sourced from various disciplines due to the interdisciplinary nature of this study. The literature provided insight into the challenges faced by communities that reside on the outskirts of urban areas and details of the relationship between land use, the associated changes and the health and quality of water bodies that occur within the catchment. The next chapter will discuss the methodology that was utilised in order to collect data as well as details of why these particular methods were adopted.

CHAPTER THREE
METHODOLOGY

3.1. Introduction

This chapter provides details about the methodology used in order to achieve the aims and objectives of this study. The methodology is mixed in nature and utilises both quantitative and qualitative data collection techniques. This chapter will first describe the chosen study area, Umhlatuzana Catchment, which is located within the province of KZN, South Africa. Thereafter, an overview of the research design and aspects of data acquisition for both secondary and primary data sources are provided. In this study, primary data was acquired using a quantitative survey and observational check sheets. This chapter will also discuss the sampling frameworks and conclude with a discussion of the techniques used for data analyses.

3.2. Description of study area

The eThekwini Municipality is approximately 2 297km^2 and is located along the eastern coast of South Africa, within the KZN province (eThekwini Municipality, 2017; Shackleton, 2010). The Municipality is home to a population of approximately 3.7 million people with an estimated 150 000 people immigrating to the city each year (StatsSA, 2018).

In 2000, as part of the ongoing post-apartheid spatial restructuring, the eThekwini Metropolitan area of 1 366km^2 was extended by 931km^2 incorporating the rural hinterlands which included but was not limited to the Folweni, Ingqunqulu and KwaMgaga tribal areas (Giraut and Maharaj, 2002; Sutherland *et al*., 2014). The peri-urban areas make up a third of the Municipality and comprise primarily of poor communities who rely on the natural environment and social grants to meet their needs (Sutherland *et al*., 2014). These communities are plagued by unemployment and poverty as well as a lack of service delivery and unresolved land tenure (Shackleton *et al*., 2010). Whilst the metropolitan area is controlled by the eThekwini Municipality, the rural and peri-urban regions are administered under the traditional authority of the Ingonyama Trust (Sutherland *et al*., 2014). The defined urban edge line demarcated the urban core and periphery and principally indicated the lack of support for bulk services in the urban periphery (Sim *et al*., 2016). The shared management of areas within the Municipality also introduces complexities in the delivery of services and overall governance of these spaces.

There is limited published research available on the communities located in the Umhlatuzana catchment. Census data from StatsSA are based on administrative boundaries as opposed to natural boundaries such as a river catchment, thus it is difficult to convey an accurate depiction of the socio-economic background for the selected communities within the catchment. Taking this into consideration, census data on the greater settlements to which the selected communities belong. The overall settlement can be described as urban, and the majority of households have access to flush toilets (inside the dwelling) and metered water provided by the local water scheme (StatsSA, 2011). Additionally, education levels predominantly range between some secondary (grade 10) and matric (grade 12), with many most household annual incomes ranging from none to R300 000.

3.2.1. Land cover and catchments

Situated on the eastern coast of KZN, the eThekwini Municipality is characterised by a 98 km coastline, 18 major river catchments, 16 estuaries, 4 000 km of river, and approximately 75 000 hectares of land which is part of the Durban Metropolitan Open Space System (D'MOSS) (eThekwini Municipality, 2017). The D'MOSS was designed to protect the city's core ecological infrastructure and provide a sustained supply of free ecosystem services to the people of eThekwini (eThekwini Municipality, 2017). Research undertaken in the Municipality has determined that four of the 14 key vegetation types present in the city are endangered, and an additional six will become endangered if transformation continues at the current rate (eThekwini Municipality, 2017). Rapid urbanisation and transformation of the landscape within the Municipality in attempting to meet development and service delivery goals and inappropriate development exacerbate threats to the region's natural environment (eThekwini Municipality, 2017; Sutherland *et al*., 2014).

There are 18 major river catchments and 12 large dams within the municipal area (Turpie *et al*., 2017). In 2010, it was found that the water quality measured at 71 of the 175 monitoring sites along the rivers of eThekwini were considered to be in poor condition and only six were classified as being 'near natural' (eThekwini Municipality, 2018). The poor condition of the water quality at these monitoring sites is a result of various impacts such as spills and illegal discharges, WWTW not operating to specification, removal of riparian flora, solid waste dumping and sand mining (eThekwini Municipality, 2017). Sand mining along with the damming of rivers within the municipality has reduced the natural supply of sediment to

Durban's shoreline by 67%, disrupting the natural replenishment of sand dunes, which act as buffers against sea level rise, storms, and other tidal events (eThekwini Municipality, 2017).

This study focuses on the Umhlatuzana catchment due to the diversity of land uses within the catchment as well as the impact of the river on households and the water quality of the Durban Harbour (Figure 3.1). The Umhlatuzana catchment consists of 14 small suburbs of diverse racial groupings, economic status and, access to services. The catchment is approximately 94.42 km^2 in size and is used for a variety of land activities such as industrial, formal urban settlements, informal urban settlements and agricultural activities (Moodley *et al*., 2015). The Umhlatuzana River courses through the Umhlatuzana catchment and converges with the Umbilo and Amanzimnyama Rivers at Bayhead Canal, thereafter draining into the Durban harbour (Moodley *et al*., 2015).

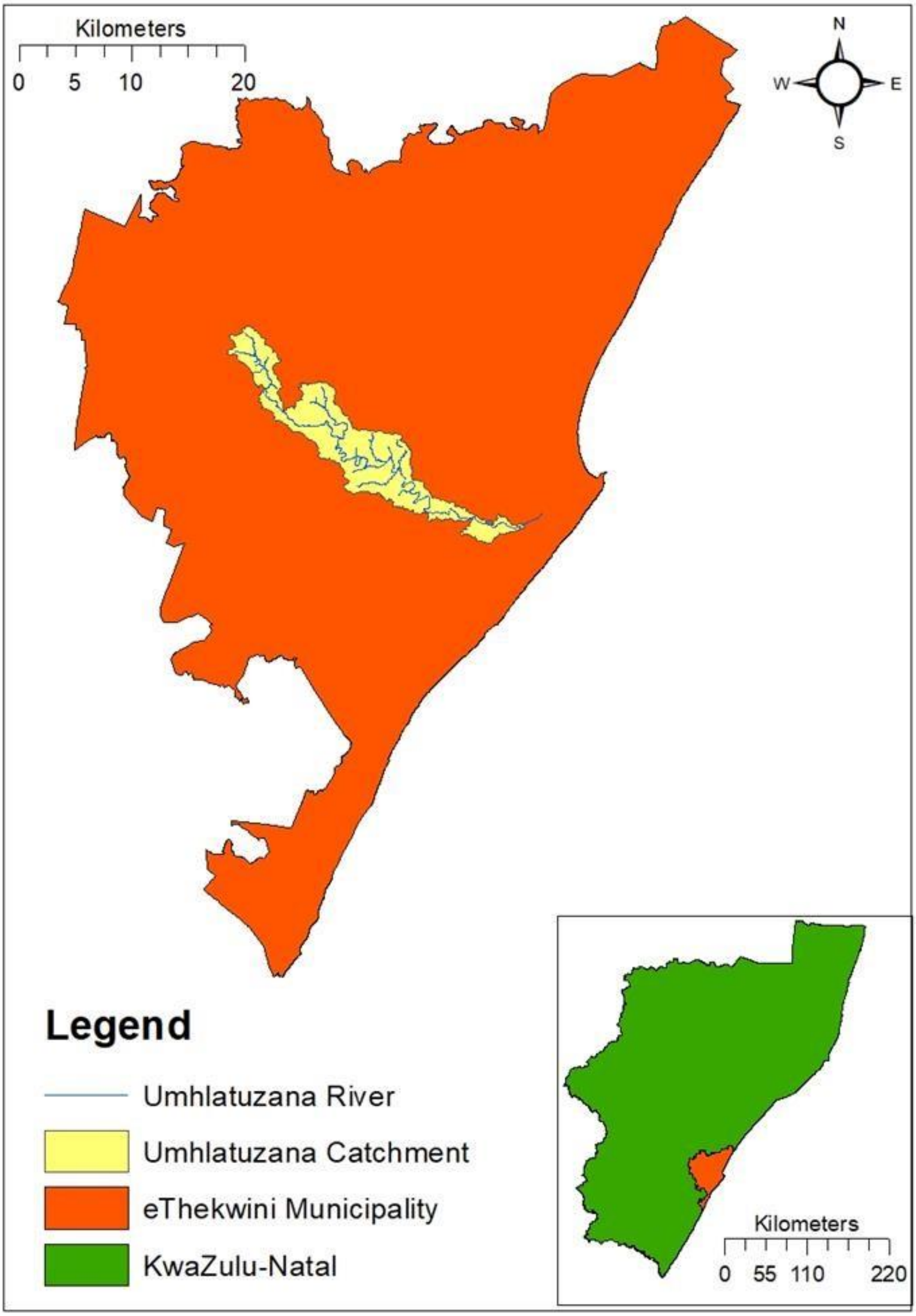


Figure 3.1. **Location of the Umhlatuzana catchment and River (Author, 2018)**

3.3. Research methodology

3.3.1. Research approach and design

Research methodology is essential for planning and guiding the research study to achieve quality and well-founded results (Håkansson, 2013). The plan created in the research methodology includes underlying philosophies used to guide the collection and analysis of data. The chosen methodological approach in this study is a mixed method approach in order to understand the lived experiences of households and the oscillations in water quality within the Umhlatuzana catchment.

Philosophical ideals are crucial to research as it assists the researcher in selecting the appropriate methodology as well as guides the approach to data (Mackey, 2005; Shannon-Baker, 2016). The selected philosophy also determines the relevance of issues and concepts to the research topic (Mackey, 2005). Phenomenology is the study of the lived world, investigating individuals lived experience of a phenomenon and has been conceptualised as a philosophy, research method and perspective for qualitative research (Converse, 2012; Sloan and Bowe, 2014; VanScoy and Evenstad, 2015). Phenomenology follows descriptive and interpretive paradigms. This study employs interpretive phenomenology, which places importance on time and space; people's realities are influenced by the world in which they live (Tuohy *et al*., 2013). Phenomenology is advantageous in this study as it is centred on personal knowledge, and places increased importance on personal perspective and interpretation (VanScoy and Evenstad, 2015). As such, the researcher is able to understand the participants' experiences, and gain insights into the lived experiences, which are critical when dealing with qualitative data.

The integration of qualitative data collection and quantitative data collection techniques has been viewed as problematic due to the differing paradigms. It has, however, also been viewed as 'the best of both worlds' as employing both methods counterpoises the weaknesses of the other (Driscoll *et al*., 2007). Mixed methodology is not a replacement for quantitative and qualitative approaches but is rather an extension, allowing for researchers to test and build theories (Williams, 2007). This research methodology can be employed at the primary level, allowing the researcher to collect qualitative and quantitative data directly from participants through observations and questionnaires for a single study (Heyvaert *et al*., 2013). Employing a mixed methodology as a research approach seeks to incorporate various viewpoints, perspectives, positions, and standpoints of both qualitative and quantitative research in a single study (Johnson et al., 2007; Doyle *et al.,* 2009). In this regard, qualitative data assists in the interpretation, description and validation of quantitative findings whilst the quantitative data allows for the generalisation of results (Johnson *et al*., 2007). The mixed method design adopted was concurrent triangulation as this typology of mixed methodologies collects both qualitative and quantitative data concurrently but independent of one another (Castro *et al*., 2010).

Triangulation employs different research methods and data sources as a means of validation of results through a convergence of findings (Martella *et al*., 1999; Johnson *et al*., 2007). Triangulation is often employed in case study research as it allows for the exploration of phenomena from multiple viewpoints, enhancing the quality of the data set and creating further validity (Baxter and Jack, 2008; Doyle *et al*., 2009). More specifically, concurrent triangulation is used in this study to triangulate two sets of data in order to verify or complement findings (Mengshoel, 2012). The water quality parameters and land use data were collected and analysed along with the results of the observations and survey data. The primary purpose of triangulation in this study is for the data to support each other as it is integrated during analysis.

In addition, this study adopted a longitudinal approach to examine changes in the water quality and land use practices within the catchment. However, household surveys and observations were carried out using a cross-sectional time horizon. This allowed for some level of verifications of perceptions and interactions. Cross-sectional studies occur at one point in time, are often descriptive and will estimate the prevalence of the outcome of interest (Levin, 2006). For this study, the outcome of interest was on how households utilised water from the Umhlatuzana River as well as how they perceived the quality of the river water. Furthermore, the study explores how sampled households perceive land use and land use change within their surrounding environment, in this case the Umhlatuzana catchment.

The research design adopted for this study is a case study approach in order to investigate socio-hydrological vulnerability within the Umhlatuzana catchment. The case study approach allows for phenomena to be investigated in a real-life context, obtaining an in-depth appreciation of what actually occurred (Noor, 2008; Crowe *et al.*, 2011). Cases are defined by the interactions that occur between various factors, with particular focus on the whole set of interactions as opposed to the contribution of an isolated variable (Bellamy, 2012). This approach allows for the use of multiple data sources, which is ultimately converged to form a deeper understanding of the phenomenon (Baxter and Jack, 2008).

3.3.2. Ethical considerations

Ethics approval for the study was provided by the University of KwaZulu-Natal Humanities and Social Science Research Ethics committee, protocol reference number: HSS/1113/015M. For the survey, all participation were provided with a thorough explanation of the research study and was informed that participation was voluntary and that all responses were anonymous. Following this, participants were required to sign a consent form agreeing to participation before the interview was conducted. Additionally, participants were informed that they are entitled to withdraw from the study at any time and without explanation. Trained fieldworkers that were conversant in the local languages and English were used.

3.4. Data acquisition

3.4.1. Data collection tools

This study uses both qualitative and quantitative data collection tools as well as secondary data sources. In order to unpack social-hydrological linkages, a quantitative survey was administered to households and qualitative observations were made. The following sections describe in detail the data collection tools as part of this study.

3.4.1.1. Questionnaire

Surveys are useful data collection tools as it makes it possible to measure the distribution of characteristics, perceptions and experiences within communities (Secor, 2010). A survey is a systematic tool which is used in order to extract data from a population, and which comprises of both open-ended and closed-ended questions (Maree and Pietersen, 2007). Open-ended questions allow respondents to express their own opinions and as such is not possible to predict. Responses to the open-ended questions were noted by the interviewer for use during data analysis. The closed- ended questions provide respondents with a list of options from which to choose and allows for the coding and quantification of answers (Maree and Pietersen, 2007).

The questionnaire used in this study comprised of the following key thematic areas (Appendix 1):

- Section A: Socio-demographic profile of respondents

- Section B: Household profile
- Section C: Perceptions and uses of land and the Umhlatuzana River.

The theoretical and conceptual frameworks used in this study guided the development of the questionnaire. Households and individuals were profiled in relation to socio-demography and water-related behaviours and perceptions. These aspects were deemed important in unpacking socio-hydrology systems. In addition, the profiles of households were important in understanding the associations with place and the external factors impacting health. Section A probes the socio-demographic profile of the household respondents. This includes attributes such as age, sex, employment status, and level of formal education. The socio-demographic attributes of the household respondent may impact their perceptions and attitude to the Umhlatuzana River (for example, level of formal education). Section B profiled the households, explored the number of household members, their ages, sex, employment statuses, household's monthly income, and highest level of formal education as well as access to piped water and electricity. This profile provides the researcher with insight about the households' levels of vulnerability as well as insight into the households' relationships with the Umhlatuzana River. Section C probed respondent perceptions of land uses within the catchment and the use and quality of the Umhlatuzana River. This section first investigated the household utilisation of the Umhlatuzana River, identifying households that use the river and understanding the frequency, duration and the reasons for use. The questionnaire further queried the general perceptions of the river, including any evidence of pollution, and the likelihood of households utilising the river if access or quality improved. The perceptions of the surrounding land uses were investigated, where respondents described changes to the river system and surrounding environment over the past 10 years. This was to understand the degree to which the households currently and in the future are likely to interact with the river and therefore the possible risks posed to their health. Additionally, it provided the researcher with insight into how the household respondents perceived changes in their surrounding landscape. All responses were anonymous, and the questionnaires stored in a safe environment only accessible to the researcher for the purposes of this study.

3.4.1.2. Observations

Observation of land use activities have revealed the impacts on the quantity and quality of groundwater and surrounding water bodies (Power, 2010). A checklist was drafted based on the objectives of the study (Appendix 2). The checklist was based on the same themes as the survey; this includes land use, demographics of users and water quality. Land use types and surrounding activities were noted, as were the number of people using the river at the time of observation. Subjective indicators of water quality such as odour and colour were observed. Lastly, evidence of pollution was listed to indicate the appearance of oil residue, sewage, litter, and detergents. The use of the checklist during observations was to ensure consistency when reporting on the various sites and was accompanied by pictures as evidence.

3.4.2. Secondary data

Secondary data is data that has previously been collected and processed and is often provided by private institutions, scientific studies and government agencies (Jensen and Shumway, 2010; St Martin and Pavlovskaya, 2010). The secondary data that was utilised in this study was spatial (2003 to 2014) and water quality data over 11 years (2004 to 2014). These dates were purposively chosen given the number of flood and drought events that occurred within this timeframe. Additionally, census data collected by Statistics South Africa (Stats SA) in 2011 was used to understand the households within the selected suburbs (for example, access to water within the household). Furthermore, land use classes and socio-demographic information and water quality data from the local municipality comprised the secondary data set.

Water quality data was obtained from the eThekwini Department of Water and Sanitation (EWS) for the period of 2004 to 2014. This data consisted of 12 sites along the Umhlatuzana River course from which samples were collected to be tested. The various physical, chemical and biological parameters selected for the study are pH, turbidity, *T. coli*, conductivity, RWQI, DO, and *E. coli*. Twelve Indicators with an incomplete dataset or missing data were excluded, this included but was not limited to magnesium, sulphate, phosphate, nitrate and nitrite. The water quality data was entered into Microsoft Excel for pre-processing and separation of the catchment into regions: upper, middle and lower catchment. Through the spatial investigation into the distribution of sampling points in the catchment the catchment was zoned into 3 regions to investigate how the water quality changes along the course of the river. This also allowed for an understanding of impacts associated with point and non-point sources and various land use types.

Records for DO levels were limited to the 2004 to 2009 (six years) period. However, as an important indicator of overall river health this parameter was included in the study. Similarly, RWQI data was collected from 2006 onwards and so the data presented is for a 9-year period. In addition to being presented in line graphs, the annual mean was calculated and the values presented on a map of the Umhlatuzana catchment. Presenting the data on a map links the water quality at each site to its surrounding environment and displays the spatial distribution of river water quality. The maps display the RWQI values for the years 2006, 2009, 2012 and 2014. Data obtained from the eThekwini Municipality for *T. coli* was recorded as integers and inequalities, as a result, years containing inequalities could not be displayed. Electrical conductivity results were converted into TDS in order to assess its possible impacts on human health and the ecology of the river. The conversion was completed using the following equation:

EC (mS/m at 25 degrees') x 6.5= TDS (mg/R) (DWAF, 1996c)

All water quality data was presented systematically in relation to the region (upper, mid or lower catchment), seasonality (major rainfall events) and guidelines for acceptable water quality (consumption and recreation). Due to the large range of recorded data for *E. coli* and turbidity, the graphs for these parameters were presented as a logarithmic scale to accommodate the variance in data (Fowler *et al*., 1998).

Spatial data was obtained from the eThekwini Department of Water and Sanitation GIS Branch. Spatial data included trade effluent points, WWTW and sewage lines, land use types, suburbs, and aerial photos. ArcGIS (v 10.3.1) was used in order to clip the land use data for 2003 and 2014 to the Umhlatuzana catchment boundary, allowing for the land use composition of the catchment to be tabulated. The spatial data was used to create a map of the study area within South Africa and in order to display the changes in RWQI in the catchment at 3-year intervals.

3.4.3. Sampling framework

Similar to other environmental studies, the spatial aspect of the phenomenon studied is of primary importance (Andreis and Bonetti, 2018). Within the Umhlatuzana Catchment, particular focus was placed on the water sampling points along the river and its surrounding communities and land uses (Figure 3.2).

The water quality dataset received from the Municipality was comprised of monthly figures for 20 sample sites. Of the 20 sites only 12 sites were selected for this study, the omitted sites had significant gaps in water quality data rending them unreliable. As seen in figure 3.2, the sites are equally distributed along the course of the river, four collection points in the upper catchment, mid and lower catchment, respectively. This distribution allows for the detection of changes as the river courses through different land uses. The water quality assessments were conducted on a monthly basis at each sample site. Since this study examined changes in water quality through a longitudinal lens, raw values for each parameter for each monthly were transferred to a database for processing. Water quality indicators are presented as annual means or in some cases both, to highlight key events. The main sample sites along the catchment were classified as upper catchment (UC), Middle catchment (MC), and Lower catchment (LC).

A multi-stage spatial sampling framework was adopted in this study for the household surveys. Important components of a spatial sampling framework include sample size and sampling scheme (Atkinson and Tate, 2000). The sample size refers to the total number of observations, in this study 12 sampling points were used as it provides detail regarding the changes of water quality along the river course (Atkinson *et al.*, 2014). The Municipality provided the coordinates of the sampling points that were equally distributed along the river course, these were used to identify regions for administration of surveys and collection of observational data. The sample sites were purposefully selected based on completeness of water quality records for the years included in the study. The next stage of the spatial sampling involved highlighting the residential typology that was within a 1km buffer of the water sampling sites. The buffer was created on the premise that households closer to the river may interact more frequently and may contribute to point and non-point sources of contamination. This was followed by field verification to assess accessibility and safety in terms of accessing the households. This approach ensured a spatially representative selection of sample sites. Figure 3.2 further highlights the distribution of these sites in relation to sampled settlements.

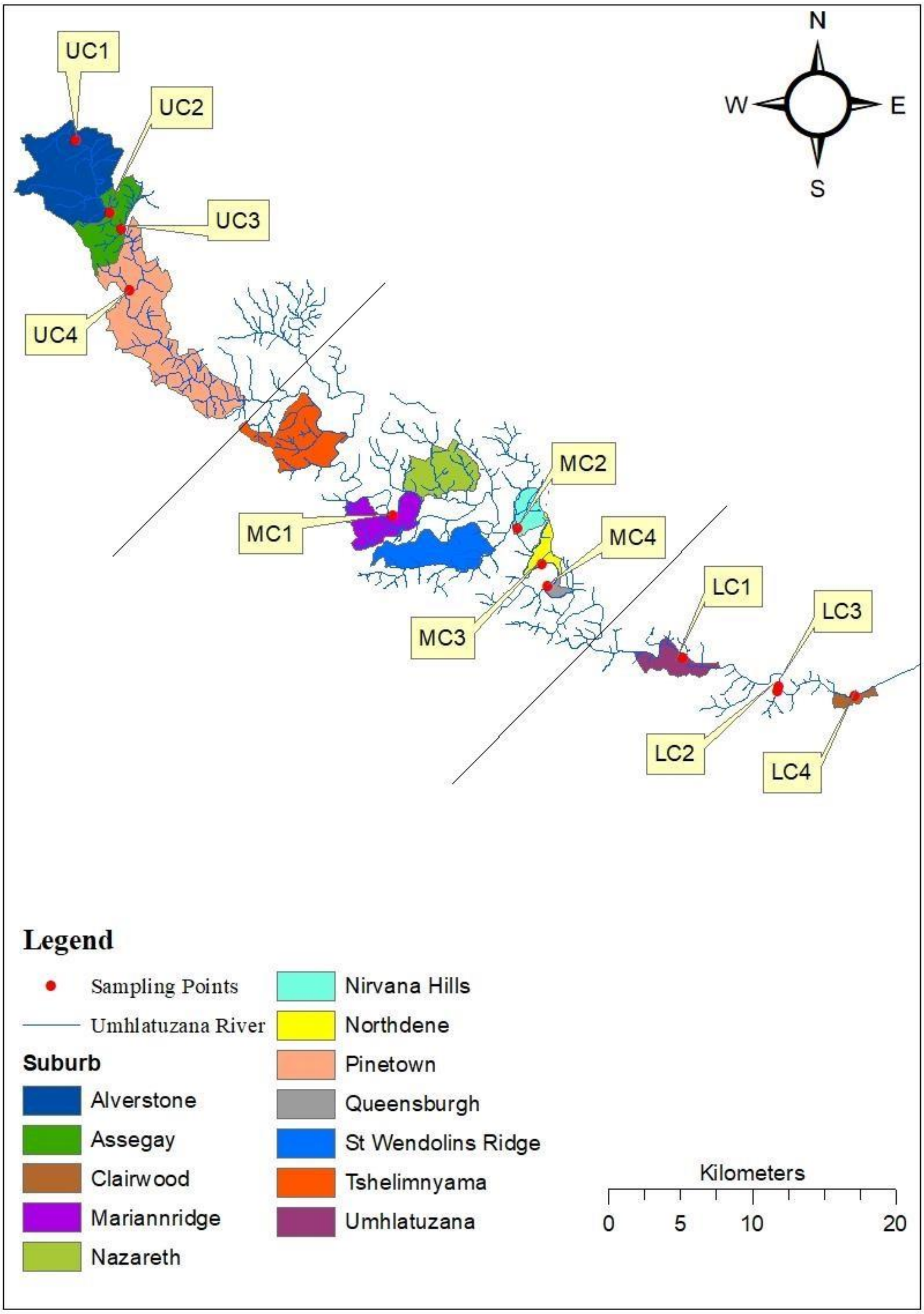


Figure 3.2. Location of sample sites and settlements used in this study (Author, 2018)

Purposive selection was utilised as the study aims to understand the experiences and perceptions of community members affected by the river, and as such households closest to the water body are more likely to contribute reliable data (Polkinghorne, 2005). Once spatial zones were identified, households within a buffer of 150 m around the main river were prioritised when administering questionnaires. Using the StatsSA 2011 census data, the total households within the identified suburbs in the catchment were estimated to equal 3593 households. Thereafter to achieve a confidence interval of 95%, a sample calculator indicated that a sample size of at least 350 households was required (Israel, 1992; Taherdoost, 2017). A total of 350 households were sampled along the catchment. The first household was selected based on accessibility and availability, thereafter every 4th household was sampled by moving systematically away from the river. Approximately 30 surveys were completed at each spatial zone and 350 surveys completed in the catchment in total. By utilising this sampling method, the researcher was able to minimise bias and ensure geographic representation of the sample population.

The survey was administered face-to-face as it allows for explanations especially in cases where the respondents may not understand a question (Maree and Pietersen, 2007). The face to-face interviews were conducted by trained field assistants and the researcher who were conversant in both IsiZulu and English. It was noted that conversations in respondents' home language made them more comfortable and willing to be part of the process. This also reduced errors in communication and improved validity and reliability of survey data.

The Umhlatuzana River was observed over a period of 3 months between August and November at the selected sample sites. This time frame (which includes, winter, spring and the beginning of summer) was selected as it accounts for the variation one may observe in different seasons. Observation sites were selected based on accessibility and proximity to formal or informal households. The researcher observed the river in the morning (before 12 midday). The observations noted included the number and demographic of individuals utilising the river as well as activities and land uses taking place nearby. Physical parameters of the river were also noted which included odour, clarity, and colour. Pictures were taken to document evidence of pollution and water use.

3.5. Data analysis

Data was analysed thematically in relation to water quality, land use type and change, and profile of sampled households. The longitudinal assessment of water quality variable provided a more detailed account for the oscillations, which assisted in the triangulation of why these occurred. The thematic examination of uses, perceptions and attitudes highlighted the main factors influencing socio-hydrological vulnerability with the Umhlatuzana catchment. As part of the data analysis both water quality and survey data were subjected to descriptive and inferential statistical testing to emphasise and verify findings. Additionally, the water quality data was evaluated by comparing it to the target ranges identified by the WHO and DWAF for domestic and recreational use.

3.5.1. Statistical analysis

All data including survey data were subjected to initial descriptive statistics to highlight key data trends using IBM's SPSS (version 25). Thereafter, for select variables, a Shapiro-Wilks test was conducted in order to determine if the distribution of data was normal. Following this and depending on the number of samples, either a non-parametric Kruskal-Wallis or Mann Whitney U test was used (with Lilliefors significance correction) to determine if there was a significant difference in parameter levels across the observed time period and between the regions of the river (UC, MC and LC) (Field, 2005). Lastly, the Spearman's Rho test was used in order to correlate the years of observation with the annual average of *E. coli* and turbidity, using the years of observation as independent variable and the water quality parameter as dependent variable. Additionally, descriptive, chi-square and correlation tests were used in the analysis of survey data.

3.5.2. GIS

ArcMap GIS software (v.10.3) was utilised in order to determine the total area for each land cover class for the associated years. Each land use type was identified, in some instances merged, to generate land use maps for each of the identified years. Once the total area for each land use typology was estimated, a basic change detection exercise (specific to area) was established. This included statistical verification of changes in total area for each typology per year. These changes were projected against water quality indicators to highlight possible trends. The longitudinal change in land use within the catchment was important in urban and environmental analyses and assisted in the interpretation and identification of relationships (Sadahiro and Kobayashi, 2014). This also assisted in visualisation of environmental change.

3.5.3. Data validity and reliability

Data reliability is most at risk when assessments are highly subjective or there are errors in a data collection instrument, which can both impact the consistency and accuracy of the data used (Drost, 2011). With reference to this study, to ensure reliability in obtaining participant information, the interviewers were trained in administering interviews with the data collection tool. This also improved on uniformity and consistency in the chosen approach. Additionally, fieldworkers were conversant in both isiZulu and English and were able to translate questions for participants for ease of communication. In addition, the translations were practiced and tailored during the training workshops for consistency in recording participant responses.

Data reliability contributes to the validity of a study, allowing for the generalisability of the results (Lakshmi and Mohideen, 2013). To this end, this study used a statistically representative calculation to determine the necessary number of households that needed to be sampled. Concerning secondary data, such as water quality and spatial data, obtained from the municipality, incomplete data sets were excluded from the analysis. Additionally, the means and standard deviations were calculated for all included datasets.

3.6. Limitations and Challenges

The selection of water quality parameters was influenced by the data obtained from the Municipality. Overall, the main concern with secondary data sources used in this study, specifically the water quality indicators, was that some parameters did not have complete data sets. For this reason, the indicators used in this study to show water quality were limited to those with complete data sets only. The *T. coli* data obtained from the Municipality were not presented in a consistent format, this created a challenge when attempting to present the absolute figures. Additionally, health data (for example, diarrhoeal incidence) from local clinics or households was not available; this would have provided greater insight into the health and wellbeing of households in the catchment.

In relation to survey data, most respondents from informal settlements were hesitant to participate due to the uncertain tenure and type of settlement. Moreover, respondents were hesitant to acknowledge their interactions with the surrounding river. Observations were made in one season (due to logistically and safety issues), monthly observations through the year at set times would have provided greater insight into any observable changes.

3.7. Conclusion

This chapter provided the details of the study area, research methodology, sampling framework, methods of data analysis and limitations for this study. The chapter discussed the justifications for the chosen methods and the associated challenges and weaknesses. The next chapter presents the results and discussion of the water quality, spatial and survey data thematically.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1. Introduction

This chapter presents the results and discussion of this study. The results comprise primary and secondary data that is thematically examined to address the research objectives outlined in Chapter One. In order to frame the results, the socio-demographic data of the respondents and their households will be discussed first. Thereafter the results pertaining to land use, water quality and communities' experiences and perceptions are discussed. This chapter presents key findings by linking it to relevant literature and water quality guidelines of South Africa and the WHO. The results are discussed in relation to the catchment as a system as well as main regions, for example, upper (UC), middle (MC), and lower (LC) catchment areas.

4.2. Socio-economic and demographic profile

An individuals' socio-demographic profile influences the possibilities and challenges that they may encounter (Abrahamse and Steg, 2011). An individual's perceptions of their surrounding environment are impacted by socio-economic factors such as levels of formal education, employment status and length of stay in community (Dogaru *et al.*, 2009). For the purpose of this study, it was necessary to consider the socio-demographic characteristics of respondents as it may have influenced water utilisation, perceptions of land use, and perceptions of river water quality.

Table 4.1: Respondent age category (n=350, in %)

Age cohorts in years	%
18-29	26.0
30-40	27.1
41-50	20.3
51-60	12.9
61-70	9.7
>70	4
AVERAGE AGE	41.8

Respondent age ranged between 18 years and 95 years, with the majority of respondents belonging to the 30-to-40-year age category (27.1%). The 18-to-29-year age category followed thereafter with 26% of respondents falling into the category and fewer (20.3%) in the 41 to 50 year age category. A smaller proportion of respondents were in the 51 to 60 year (12.9) and 61-to-70-year categories (9.7%), whilst a minority of respondents were over the age of 70 years (4%). Average age of respondents was 41.8 years, suggesting that the population interviewed was middle aged. StatsSA (2016) report similar trends on age and are typical of low-income settlements.

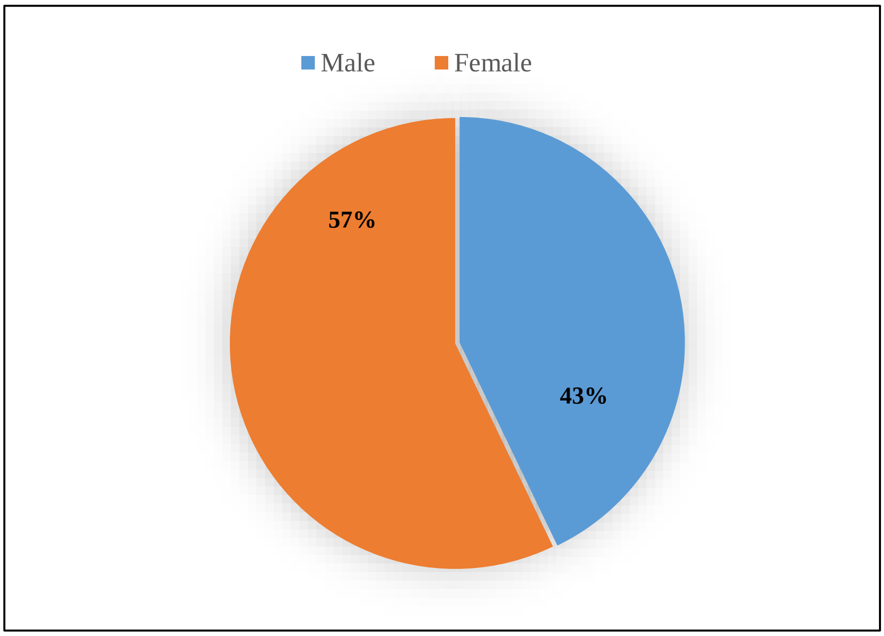


Figure 4.1: Sex of respondent (n=350, in %)

Most of the respondents were female (57.1%), while males comprised 42.9% of the population (Figure 4.1). This result may have been attributed to the sampling framework employed in the study. Surveys were administered to an adult member of the household (individuals older than 18 years) during office hours (typically Monday to Friday, 8am to 4pm). Most female respondents indicated that the male household members were absent due to work commitments. The higher proportion of females is also consistent with trends highlighted in Census data (StatsSA, 2016).

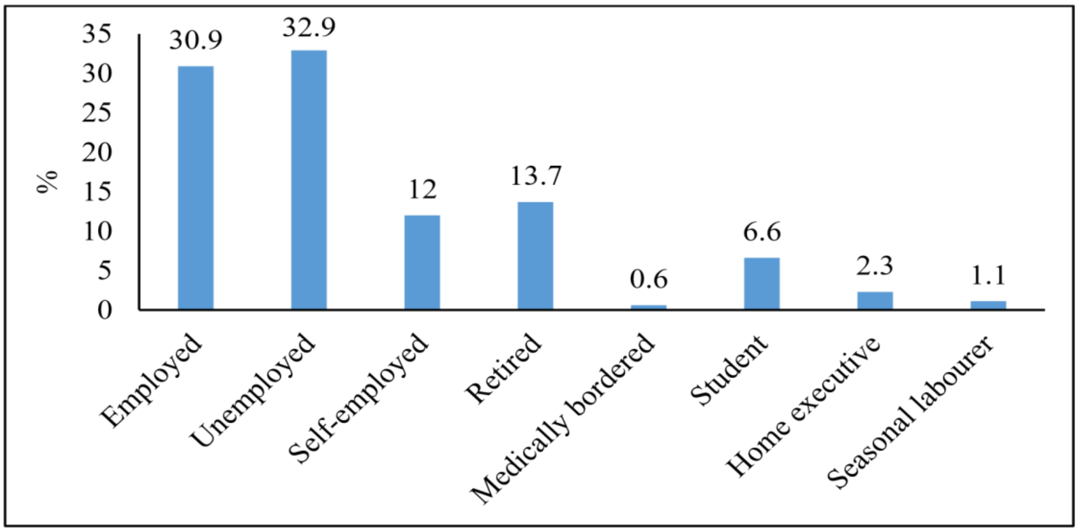


Figure 4.2: Respondent's employment status (n=350, in %)

Employment status was probed in order to provide greater insights into the socio-demographic profiles of respondents in the sampled population (figure 4.2). Only 30.9% of respondents are formally employed and a further 12% were self-employed. The majority of respondents did not have formal employment (32.9%). An additional 13.7% were retired and 6.6% were students, indicating that they do not earn a salary, adding to the number of dependants in the household. This raises concern about the sustainability and livelihood security of households. Underemployment and unemployment may be a challenge for the sampled communities. The results above indicate that a greater proportion of respondents contribute to dependency in the household, highlighting their socio-economic vulnerability. The unemployment rate among respondent households exceeds the municipal unemployment rate of 21.8% in 2018, this is characteristic of vulnerable households in a municipality with a shortage of employment (StatsSA, 2019).

Table 4.2: Respondent highest level of formal education (n=350, in %)

Level of education	**%**
No formal education	3.7
Partial primary	5.4
Primary	2.9
Partial secondary	21.7
Secondary completed	33.1
Certificate/ diploma	20.9
Undergraduate degree	7.7
Post graduate degree	3.4
Adult-based education	1.1

Most respondents (87.9%) indicated partial secondary schooling or higher in relation to levels of education. More specifically, respondents indicated secondary level (33.1%), partial secondary (21.7%), diploma (20.9%) level training. Smaller proportions noted undergraduate degree (7.7%), post-graduate degree (3.4%) and, adult-based education (1.1%) as their highest level of education. A collective 65.1% of respondents have attained a national senior certificate (secondary schooling completed). This may improve employment opportunities as well as affect their perceptions of the surrounding environment. Approximately 33% of respondents had partial secondary level of less. This is concerning given that the majority of the population were in the economically active group. The lack of formal training and schooling will impact employment potential.

Table 4.3: Respondent's monthly income (n=350, in %)

Income range	%
None	30.3
<R1500	8.3
R1500-3000	19.1
R3001-4500	6.0
R4501-6000	5.7
R6001-7500	6.0
R7501-9000	5.9
R9001-10500	3.4
> R10500	12.6
Did not disclose	0.6

Of the selected households, two respondents declined to reveal their monthly income. Just over 30% of respondents indicated that they do not receive a monthly income and a further 8.3% indicated that their monthly income was less than R1 500 (Table 4.3). A smaller portion indicated that they receive a monthly income between R1 500 and R3000 (19.1%), whilst an equal 6% indicated that their monthly income ranges between R3 001-R4 500 and R6 001-R7 500. The remaining respondents' monthly income varied between R4 501-R6 000 (5.7%), R7 501-R9 000 (5.9%), R9 001-R10 500 (3.4%), and more than R10 500 (12%). The average monthly income for the sampled households is R11 531.41; this is slightly more than the KZN average of R8 424. Although 32% of respondents indicated that they are unemployed, only 30% indicated that they do not receive an income. This may be due to receiving remittances that assist with supporting the household.

The diverse income ranges of respondents illustrate the heterogeneous nature of the peri-urban community, as well as the income disparities in South Africa. In these communities, households with greater income have better access to resources and infrastructure in comparison to the lower income households (Vemerink *et al*., 2011).

In order to understand household level vulnerability in the catchment, the survey probed household characteristics and socio-economic profile. Respondents described sex, age distribution, employment and level of education, income sources and livelihood activities that characterised their households.

Table 4.4: Respondent household demographics (n=350, in %)

Household demographics	**%**
Sex	
Male	48.3
Female	51.7
Age cohorts	
0 to 9	16.8
10 to 19	16.2
20 to 29	19.8
30 to 39	15.2
40 to 49	13.5
50 to 59	9.3
60 to 65	3.5
Older than 65	5.6

The gender distribution of household members in the study sample is fairly even with 51.7% of members being female and 48.3% male (Table 4.4). The results indicate that 19.8% of household members are between the ages of 20 and 29 years. A collective 33.0% of household members are under the age of 19 years and 9.1% are over the age of 60. With a total of 52.8% of household members under the age of 30, the sampled household indicate a youthful population. This is necessary to note as it provides greater context when considering the uses of river water and perceptions of water quality and land use. Additionally, households on average consisted of 4.5 members, with a minimum of 1 member and a maximum of 15 (SD= 1.97).

Table 4.5: Accumulated monthly household income (n=350, in %; Multiple responses permitted)

Income source	%	Average Income (in Rands)	Min	Max	SD
Formal employment	51.4	R13 103.06	R800	R70 000	R11 565.99
Small business/ informal trading	12.0	R9 382.14	R450	R45 000	R8 712.24
Sale of agricultural produce	0.9	R17 500.00	R2 500	R30 000	R13 919.41
Remittances	3.4	R 2 483.33	R300	R10 000	R3 031.00
Pension	27.7	R2 068.04	R1 500	R11 500	R1 191.16
Child grant	27.7	R647.44	R150	R6 000	R719.22
Disability grant	3.7	R1 437.69	R390	R2 000	R470.07
Room/ house rental	0.9	R4 833.33	R1 500	R11 500	R5 773.50
Monthly household income	**R11 911.59**		**R350**	**R85 000**	**R11 969.06**

The results in table 4.5 indicate that 51.4% of households derive their monthly income from formal employment while equal proportions of households (27.7%) derive their income from pension or child grants. A further 12% of households derive their monthly income from small businesses or informal trading sales. Equal proportion of households (0.9%) derived monthly income from the sale of agricultural produce or room/house rental offerings. Other income sources included disability grants (3.7%) and remittances (3.4%). A collective 59.1% of respondents indicated that the household collected some sort of governmental grant (disability, child or old age pension grants), totalling a monthly average of R4 071.27. The level of reliance on the state as a source of income is concerning.

The average monthly household income is R11 531.41 which is attributed to the sales of agricultural produce (x= R17 500) and formal employment (x= R13 103.06). The income generated by agricultural produce is noteworthy in this sample. Despite only 0.9% of the respondents claiming to derive an income from this source, the average income gained was 33.6% greater than the income obtained through formal employment. Further discussions revealed that the type of farming activity was commercial sugar cane cultivation, which could explain the higher incomes. The standard deviation and minimum and maximum provided in the table shows the variation of household income in the catchment. Although the average income is high, many households in the catchment do not have enough to support their household and satisfy their needs.

Within this community, there are vulnerable and dependent households that are evidenced by the high dependency on social grants (more than 50% of households' access state grants). This indicates that the grant beneficiaries require government assistance to meet basic needs (this may be due to injury/illness, being elderly or mothers who are unable to provide for their children) (Sinyolo *et al*., 2016). The limited sources of income suggest that paid services such as water and sanitation may be financially inaccessible to these households. More importantly, the population sampled can be classified as young or middle aged, which constitute the portion of economically active citizens. The high levels of dependence on the state to generate income is concerning since this places significant burden on government to meet demand for services whilst providing financial aid to such communities. For developing countries such as South Africa, this trend is worrying, and some efforts need to put in place to reduce state reliance. This could allow for some of the funds to be used for aspects such as housing and basic service provision.

Outside of formal structures, it is common for household members to engage in income generating options, especially within the informal sectors. This trend is common among developing countries. The survey probed on the various activities that households engage in to sustain their livelihoods. The results indicate that 85.4% of households did not engage in any livelihood generating activities. A few (9.7%) of the respondents indicated that a member of the household engaged in spaza shop/ business activities on their premises. The remaining activities that took place on the property included crop production (2%), crafting (1.4%), livestock rearing (1.1%), traditional medicine production (0.9%) and production of building blocks (0.6%).

Limited engagement in livelihood activities indicates a lack of diversification of income streams, which increases the risk for household's poverty. Agricultural activities may act as a coping strategy in alleviating hunger in the household, additional produce could also be sold or bartered for other household essentials. The lack of crop production or livestock rearing and the dependence on state grants increases the vulnerability of households for young, poor households (Paumgarten and Shackleton, 2011). The limited activities could also speak to poor tenure security and rights to land. Some of the population sampled resided in informal settlements. Conditions within these types of settlement may not lend itself to livelihood options such as subsistence farming.

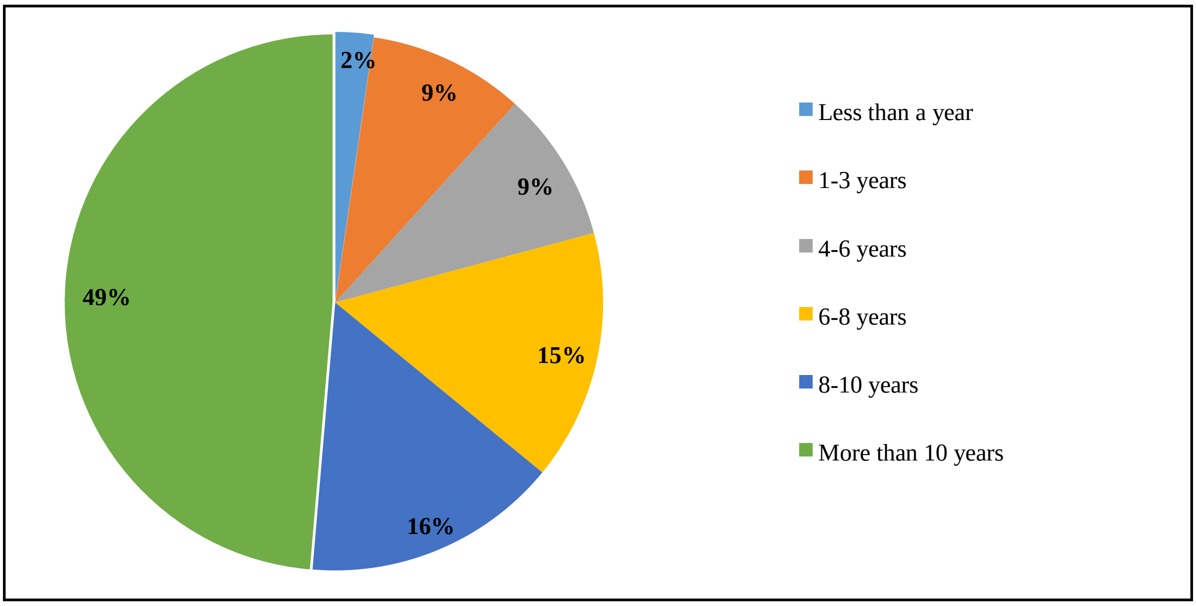


Figure 4.3: Total years household has occupied the area (n=350, in %)

A noteworthy 48.6% of respondent households resided in the community for more than 10 years (figure 4.3). A smaller proportion indicated periods 8 to 10 years (15.4%), 6 to 8 years (15.1%) and 4 to 6 years (9.1%). A minority of respondents indicated that the household inhabited the area for less than a year (2.3%), and 9.4% indicated that the household inhabited the area for 1 to 3 years. Individuals who have resided in the community for at least 10 years are more likely to be aware of the changes in the river as well as changes in the surrounding land use activities. Residents of less than 2 years may only provide a snapshot of recent occurrences of pollution or may have only observed the river once it had deteriorated with no reference of its previous state. The long-term exposure to the conditions of the catchment is seen as an opportunity to probe perceptions and understandings of the nearby water source and changes in surrounding land uses. This also, plays a key role in how households view and understand their socio-hydrological linkages.

Table 4.6: Distribution of household dwelling type (n=350, in %)

Dwelling type	**%**
Formal brick	94.9
Traditional	1.7
Informal materials	3.4

The household survey took cognisance of the dwelling type of households, energy requirements, and access to sanitation and potable water. Respondents' households were 94.9% formal (having used formal building supplies such as brick and cement), 1.7% traditional (built with traditional materials such as mud and thatch), and 3.4% informal (using informal building resources such as corrugated iron, wood, and cardboard which is usually constructed by the household members) (Table 4.6). Most notable is that most households were built with formal building supplies, considering some households were sampled from informal settlements.

Table 4.7: Household main energy source for heating, cooking and lighting (n=350, in %)

	Heating	Cooking	Lighting
Electricity	90.3	81.7	96.0
Gas	2.9	10.6	-
Fuelwood	5.1	2.3	0.6
Paraffin	0.6	5.4	1.4
Solar	0.6	-	-
Candle	-	-	2
None	0.6	-	-

The main source of energy used in households in the catchment (Table 4.7) is electricity as over 90% of households use it for heating (90.3%) and lighting (96%). Other sources of energy for heating in the household was fuelwood (5.1%), gas (2.9%), paraffin (0.6%) and solar (0.3%). The majority (81.7%) of households identified electricity as the main source of energy used for cooking. Thereafter the main source of energy used for cooking was gas (10.6%), paraffin (5.4%) and fuelwood (2.3%). The vast majority of household in the catchment made use of electricity for lighting (96%), other households rely on paraffin (1.4%), Fuelwood (0.6%) and candles (2%) as their primary source of energy for lighting. The use of electricity as the main energy source in catchment households (particularly for lighting) is noteworthy considering households were also sampled from informal settlements. This access to electricity may be due to upgrading programmes that intend to improve infrastructure access in informal settlements as an attempt to reduce poverty (Kovacic *et al.*, 2016).

Table 4.8: Household access to sanitation (n=350, in %; Multiple responses permitted)

Sanitation	%
Flush toilet inside dwelling	77.1
Flush toilet outside dwelling	24
Pit latrine	6.6
Nearby river/water body	0.3
Communal Ventilated Improved Pit toilet (VIP)	0.9

A noteworthy 77.1% of respondents have access to a flush toilet within a dwelling and a further 24% of respondents indicated that the household has access to a flush toilet that is not inside the dwelling but is within the premises (Table 4.8). Other sanitation types to which households had access to were pit latrines (6.6%), communal VIPs (0.9%) and the nearby Umhlatuzana River (0.3%). Although, a relatively small proportion, the fact that the river is being used to dispose raw, untreated sewage may contribute to water quality specifically, levels of *E coli*. Additionally, poorly constructed/ managed pit latrines may leach and therefore contaminate groundwater, threatening human health (Graham and Polizzotto, 2013; Back *et al*., 2018).

Table 4.9: Household access to water (consumption and domestic use only) (n=350, in %; Multiple responses permitted)

Potable water	**%**
Metered water within dwelling	81.1
Outside tap on plot	42.3
Communal standpipe	8.6
Borehole	0.6
Umhlatuzana river	14.6
Harvested water (rainwater)	4.3

Most households (81.1%) had access to metered water within the dwelling, however, it is interesting to note that despite this, 42.3% noted metered tap on the plot but outside of the dwelling as their source of water. Other sources of potable water included communal standpipes (8.6%), harvested rainwater (4.3%) and boreholes (0.6%). From the results (table 4.9), it is evident that households make use of more than one water source for their needs. Several households (14.6%) used the Umhlatuzana River as a source of potable water.

Household profiles reveal that most households (94.6%) had formal dwellings, this is interesting to note since 31.94 % of households resided in informal settlements. Similar trends were noted with electricity and to a lesser extend access to treated potable water. This could be explained by the municipal initiative aimed at providing interim formal services and dwellings to informal residents. However, despite this, households still used untreated water from the river. Although physical accessibility to metered water in the catchment is prevalent, limited financial accessibility to basic services is common in the country as similar trends are noticed in relation to energy (Munien, 2016). Literature indicates that lower income households may make use of community standpipes and nearby sources that are deemed free, such as a dam or river, for domestic activities as they fear debt collection and imposed droughts (Mathekganye *et al*., 2019). As a result, the households are increasingly vulnerable to hydrological changes in the catchment. The geography and socio-demographic profiles are important variables to consider when examining health and access to basic services. Especially in South Africa where the legacy impacts of discrimination and racially based occupation of land are prominent. In addition, the place perspectives, as discussed in Chapter 2, underpin access to basic services and improved environmental conditions within the South African and developing contexts, more broadly.

Specific uses, frequency of use and perceptions are discussed in subsequent sections in relation to water quality assessments. Additionally, the majority of households (49%) have resided in the catchment for more than 10 years, which assisted in understanding how space and place is conceptualised, particularly as it relates to health of the individual and their community (Dlamini *et al.*, 2020).

In keeping with the systems approach adopted in this study, an overview of historic and current land use practices are provided in the section below. Land use and water quality are integrally linked and could explain the changes in water quality and overall catchment health. The years included for analysis was based on completeness of municipal records, and corresponding water quality assessments.

4.3. Land use

Land use practices have altered natural landscapes for human uses such as agricultural activities, industry and urban centres. Figure 4.4 displays the land uses occurring within the Umhlatuzana catchment. Spatial data obtained from the eThekwini Municipality was analysed in order to determine the land use changes that have occurred in the catchment. These have been discussed in relation to literature. Spatial data is further enhanced through observations recorded at various sites along the catchment.

The map presents the main land uses according to three segments: UC, MC and LC areas. Land use patterns of the catchment was examined from 2003 to 2014. Results show that land use in the catchment can be characterised as mixed with urban settlements and agriculture being the dominant types. It is important to note that both informal and formal settlement activities are prevalent in the catchment. The other land uses witnessed in the catchment, but to a lesser extent, include vacant land, commercial/retail, industrial, under construction, state/ institutional, water bodies and transportation activities (railway, road). Furthermore, land use patterns indicate that the UC, MC and LC show differences in the dominant practices. For example, the UC area shows agriculture, vacant land and urban formal settlement to be the main land uses. The MC shows that formal settlement, informal settlement and the land to be the dominant land uses. In the LC the dominant land uses are formal settlements, undeveloped land and industrial areas.

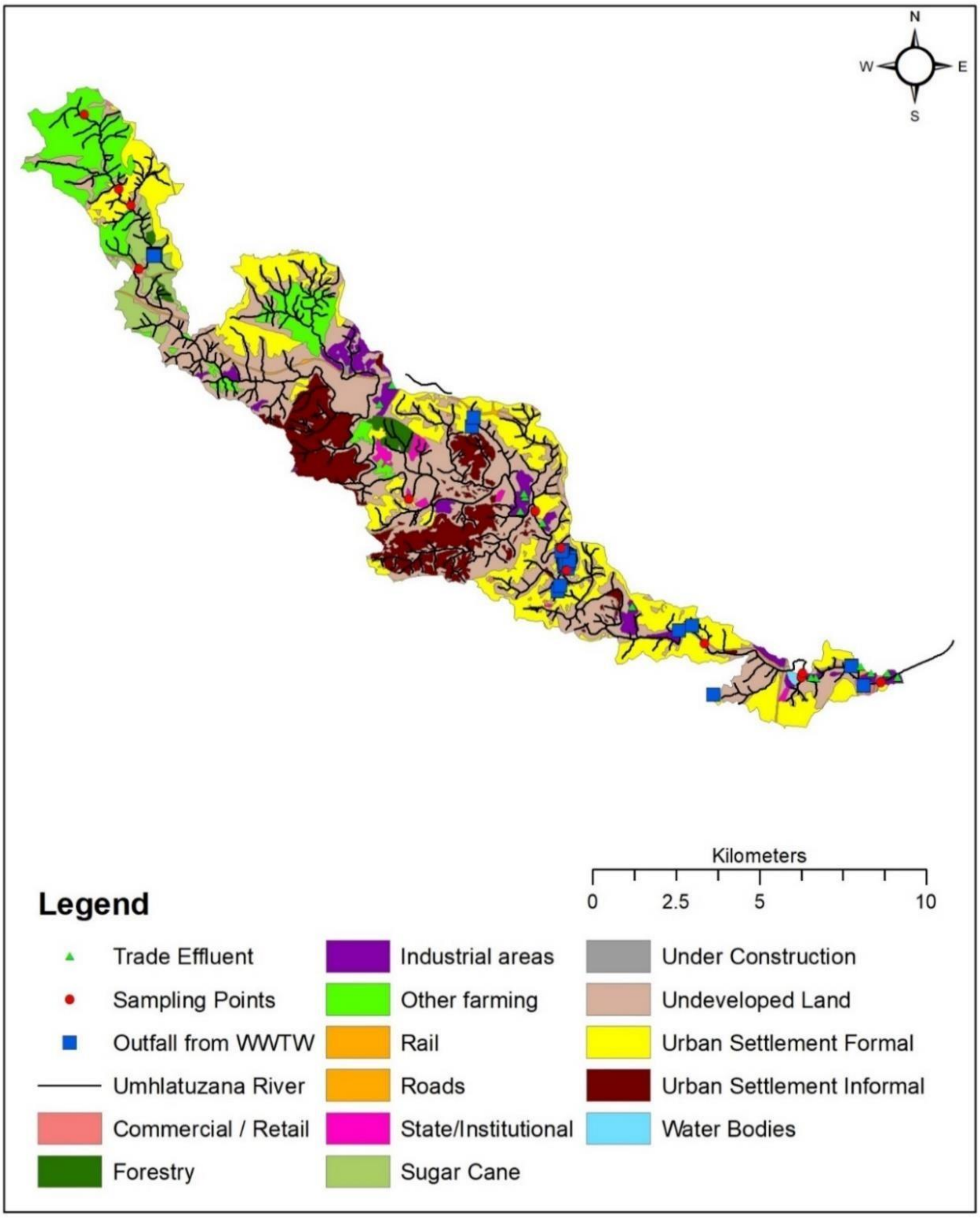


Figure 4.4: Map presenting land uses in the Umhlatuzana catchment in 2014 (Author, 2018)

In the Figure 4.4 above, it is evident that the upper course of the river is dominated by sugar cane plantations, other types of farming, formal settlements and areas of vacant land. Through ground truthing and field observations small-scale crop cultivation and livestock rearing were also prevalent, but to lesser extent. The dominance of different types and scales of agriculture within this zone will influence water quality. More specifically, given the types of agriculture (sugar cane and livestock) sediment levels and thus turbidity is expected to be of concern. Informal and formal settlements are concentrated around the middle course of the river, accompanied by small pockets of industrial land use. The lower course of the river is dominated by urban settlements, with several industrial areas occurring along the main river line. Several WWTW are present in the upper and middle catchment areas. The industrial areas present in the middle and lower catchment areas are in close proximity to trade effluent outlets.

The activities dominating the lower and middle catchments can be described as high to water quality, specifically the WWTWs and industrial type land uses. These regions show higher concentrations of informal settlements, which are typically under serviced in relation to formal water connections and solid waste removal. As a result, illegal dumping of solid domestic waste is a major concern. Several dumping sites as well as burn sites were noted in close proximity to the river during the field observations. A more concerning observation was that there were a few sites along the lower and middle catchment that showed evidence of dumping industrial effluent. The accumulative effect of solid domestic waste and industrial effluent dumping on will have detrimental impact on river and catchment health and, water quality. Clearly, there is intense and diverse land uses within the catchment. The next section provides a quantitative account of land uses and shows the change in area and percentage cover (relative to the entire catchment area).

Table 4.10: Land use typologies and % change over the study period within the Umhlatuzana catchment

	2003		2014	
Land use zoning	**Area km^2**	**%**	**Area km^2**	**%**
Commercial/retail	0.26	0.27	0.26	0.27
Forestry	1.19	1.26	1.19	1.26
Industrial areas	3.59	3.80	3.96	4.19
Other farming	10.86	11.50	10.90	11.54
Transport	1.26	1.33	1.26	1.33
State/institutional	0.84	0.89	0.84	0.89
Sugar cane	3.80	4.02	3.58	3.79
Under construction	0.41	0.43	0.04	0.05
Vacant land	37.08	39.27	36.68	38.84
Urban settlement formal	23.63	25.04	24.23	25.66
Urban settlement informal	10.39	11.00	10.35	10.97
Water Bodies	1.13	1.19	1.13	1.20
Catchment total size	**94.42km^2**	**100**	**94.42km^2**	**100.00**

Over the period, several land uses showed no notable changes in size, these were namely, commercial, forestry, transportation, state land and water bodies. The most notable changes in land use (table 4.10) were observed in industrial areas, the occupied area increased by 0.4% (0.37 km^2), and construction zones declined from 0.41km^2 in 2003 to 0.04 km^2 in 2014. The area occupied by informal settlements declined by 0.03% whilst formal settlements increased in size, from 23.63 km^2 to 24.23 km^2. Sugar cane farming activities reduced from 4.02% in 2003 to 3.79% in 2014, however, the remaining agricultural activities exhibited a minor increase of 0.04km^2. The total vacant land declined by 0.4 km^2 (0.43%).

Although no noticeable changes were recorded from informal settlements, satellite images and orthophotos show an increased density within these zones. Municipal level control may have assisted in curbing physical expansion of these informal settlements; however, images show greater intensity of this land use type (Figure 4.5). Figure 4.5 shows the change in density of an informal settlement (2003 to 2014). More concerning to note are the trends in the 2014 image as the density of the settlement increases. It is necessary to note that the change in density of various land uses is equally important as the change in the defined boundary. The increase in density is likely to result in an increase in pressure on the landscape, compounding existing challenges such as access to sufficient water and sanitation services, increasing the vulnerability of this community.

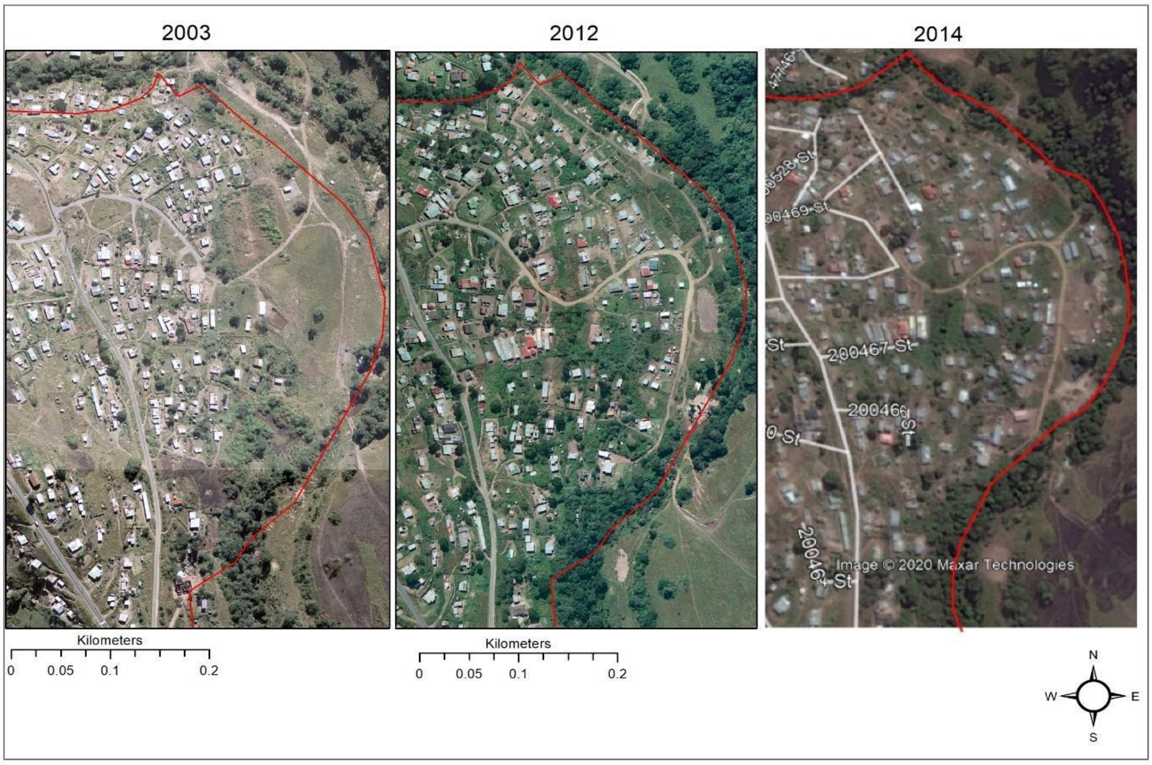


Figure 4.5: Increased densities within informal sectors in the middle catchment for the years 2003, 2012 and 2014 (Author, 2018)

Within the map of land uses commercial sugar cane farming and other farming activities are concentrated around the upper catchment area. Increased sediment runoff from agricultural activities and urban settlements could contribute to increased river turbidity levels. Farming activities, particularly commercial, requires periods of soil to be left bare, the use excess nutrients and pesticides to ensure the well-being of crops (Foley *et al*., 2005; Nyenje *et al.,* 2010). These practices could increase amounts of sediments carried by surface runoff increasing sediment loads to nearby water bodies. According to Martinelli and Filoso (2008), excess sediment loads particularly, from agricultural sites can increase nutrient loads within river systems. The upper catchment area is dominated by formal settlements, typically characterised by impervious surfaces and increased runoff. Urban settlements are often associated with ecosystem loss due to the clearance of vegetation for infrastructure and development (Grimm *et al*., 2000; Paul and Tonts, 2005). The pollutants in the surface runoff of urban settlements are diverse due to the variety of activities occurring, including domestic chemicals, backyard mechanics and urban gardening (Malmqvist and Rundle, 2002). The combination of these land uses would result in greater particulate matter in surface water resulting excessive turbidity.

Land use change in the catchment itself affects river health particularly when developing vacant land. In table 4.10, vacant land has decreased from 37.08km^2 to 36.68km^2, this change of natural landscape for human use and formal residences may affect biodiversity levels, drainage and may result in ecosystem destruction (Pinto and Masheshwari, 2011; Malmqvist and Rundle, 2002). The presence of construction activities often places pressure on available water sources due to surface runoff and construction wastage as well as construction activities requiring large amounts of water (Shen and Tam, 2002). Within the catchment, construction activities decreased by 0.38% whilst industrial land use and formal settlements increased. There was also a decline in informal settlement size, allowing for the assumption that the formal replaced informal settlements and that industrial replaced construction land uses.

Formal and informal settlements dominate the land use activities in the middle segment of the catchment area. Informal settlements often lack sufficient access to water and sanitation, and as a result, households may utilise nearby water bodies in order to satisfy their needs, increasing the likelihood of sewage pollution (Bond, 2014; Okurut *et al*., 2014). Trade effluent points are present in the middle catchment, adjacent to the main river and its tributaries. The presence of trade effluent outfalls in conjunction with the increased impervious surfaces characteristic of urban settlements, contributes to the presence of colloidal matter and suspended particles in the river (Yang *et al*., 2015). Visibility in the river would be poor, reducing the ability of predators to sense prey and vice versa (Leahy *et al*., 2011). The increased turbidity would also provide particles upon which parasites and microbial contaminants may settle, exacerbating the health risks to informal households within the buffer (Yang *et al*., 2015).

The dominant land use type in the lower catchment is formal urban settlements. Numerous industrial areas occur along the main river along with trade effluent points, particularly at the end of the river line, where the Umhlatuzana converges with the Umbilo and Amanzimnyama rivers at the Bayhead Canal. The presence of industrial outlets could affect water quality, specifically DO, turbidity and ph. The presence of industrial activities increases the likelihood of pollution from industrial wastewaters (Malmqvist and Rundle, 2002). Industrial wastewaters differ according to the activities taking place, but may include heavy metals, grey water, industrial sludge and heat pollution, increasing turbidity and reducing DO levels (Oelofse, 2010). Specific water quality variables are examined in detail in the subsequent sections. The presence of industrial and construction activities in proximity to informal settlements and lower income formal residential settlements (in the MC and LC) increases the communities' exposure to water pollution and environmental degradation (Dlamini *et al*., 2020). This is noteworthy as households who use the river water for domestic activities are vulnerable to degradation caused by industrial effluent. Additionally, the presence of industrial land use activities in the MC and the LC informs how respondents in the MC and LC conceptualise space and place in relation to health.

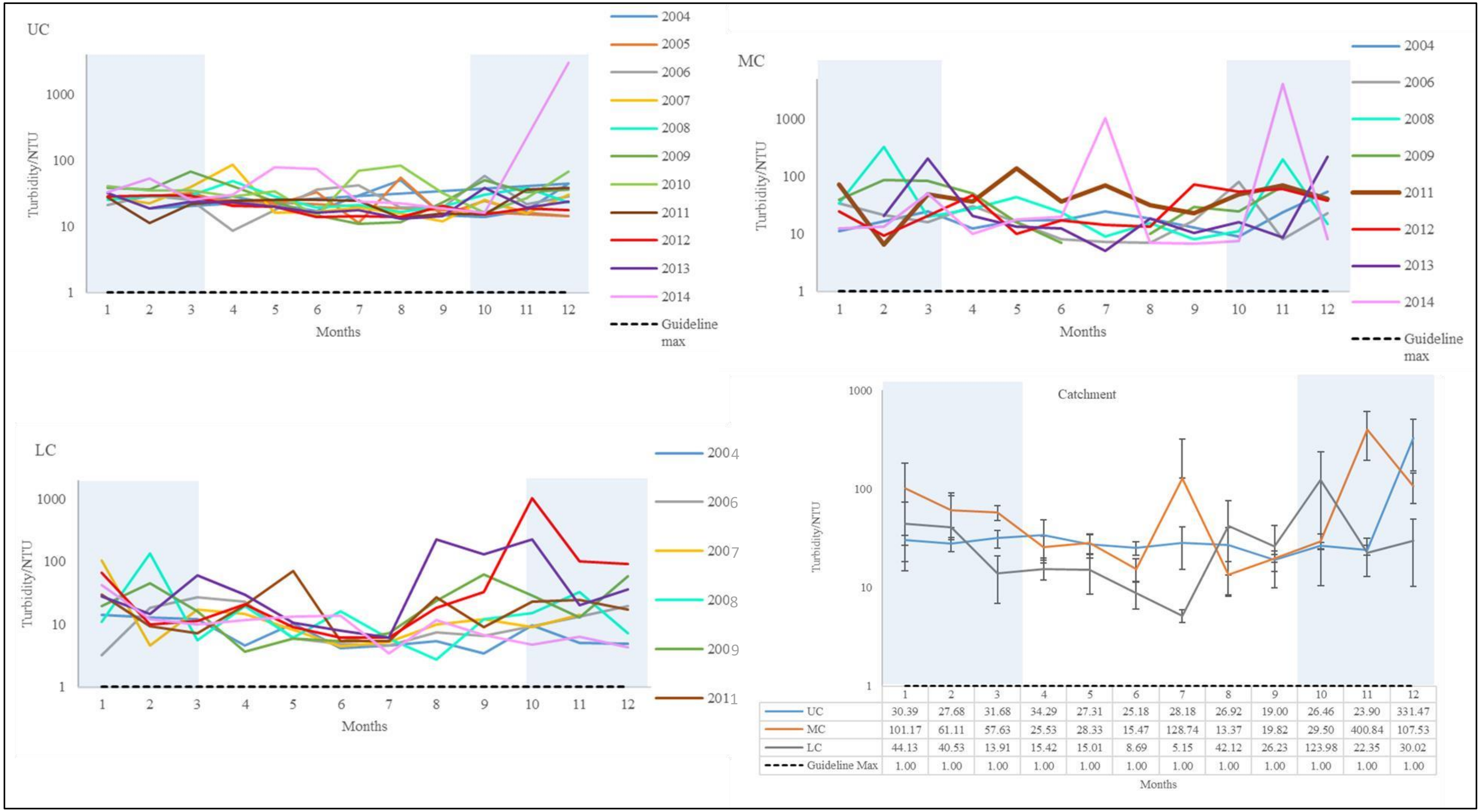
Informal settlements are often located in less desirable areas which are in proximity to natural resources as well as ports, markets, airports and industry as for many inhabitants, this is their place of employment (Inglehart, 1995; Satterthwaite *et al*., 2020). The geographic location of settlements is important when considering potential exposure to environmental risks and the resultant effects on the health of a community. Moreover, the location of informal settlements on cleared marginalised land which is close to resources (such as floodplains), results in the households being vulnerable to hydrologic events such as flooding (Dalu *et al*., 2018; Williams *et al*., 2019). However, for many households, this risk may be considered as acceptable as the proximity to urban opportunities and essential resources such as water is of greater importance Williams *et al*., 2019). As discussed in chapter 2, informal settlements lack appropriate access to basic services, due to South Africa's political legacy as well as corruption in municipal service delivery, highlighting the influence of geography on health.

4.4. Water quality

The water quality data in this chapter is analysed according to the six selected water quality parameters. In each case the trends of the entire river are presented and discussed, thereafter water quality is discussed in relation to the three main areas: UC, MC and LC. Sample sites are numbered and coded as R-ZANA by eThekwini, which represents River Umhlatuzana, in this study the samples sites are referred to site 1 to 4 (in sequence from source to mouth). A period of 11-years was observed for each chosen parameter, however, a period of nine years for the RWQI and 6-years for DO is being observed, as data obtained from eThekwini Municipality was incomplete. The following results are divided according to UC, MC and LC, each displaying the monthly values over a period of 11-years. Monthly examination of water quality highlight spikes and dips in relation to seasonality and peak flow regimes; these trends may not be prevalent when examining yearly averages.

4.4.1. Turbidity

Turbidity refers to the degree of clarity of a water body and is often associated with the general drinkability of a water source by consumers (WHO, 2011). As presented in the literature review, the WHO limits turbidity levels in drinking water to five NTU whilst SAWQG outlines 1 NTU to be the maximum levels permitted for domestic use. The results are displayed in graphs and presents the monthly turbidity values in the UC, MC, and LC as well as the annual averages and overall trend.



	1	2	3	4	5	6	7	8	9	10	11	12
UC	30.39	27.68	31.68	34.29	27.31	25.18	28.18	26.92	19.00	26.46	23.90	331.47
MC	101.17	61.11	57.63	25.53	28.33	15.47	128.74	13.37	19.82	29.50	400.84	107.53
LC	44.13	40.53	13.91	15.42	15.01	8.69	5.15	42.12	26.23	123.98	22.35	30.02
Guideline Max	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Figure 4.6: Mean monthly turbidity levels (2004-2014) within segments of the Umhlatuzana Catchment

The distribution of turbidity in the UC ranged between 10 NTU and 3 000 NTU in figure 4.6. This range exceeded the upper limits of the SAWQG-DU (DWAF, 1996a). Several spikes in turbidity levels were noted for 2014 in the UC and MC, specifically in the moths of June to July and October to December, with the most notable being 3 000 NTU in December 2014. In the MC, turbidity levels ranged between 5 NTU and 4 001 NTU. Peaks in turbidity occurred in several months of the year, most notably in July and November of 2014 1 013 NTU and 4 001 NTU, respectively. In the LC spikes in levels were noted for multiple years (2008, 2001, 2012 and 2013), and levels ranged between 3 NTU and 1 000 NTU. Generally, mean turbidity levels increased significantly in the UC (p= 0.012), MC (p= 0.0001) and LC (p= 0.0001) from 2004 to 2014. The peaks in turbidity for the months of June and July can be explained by limited rainfall and therefore reduce flow and water levels (winter).

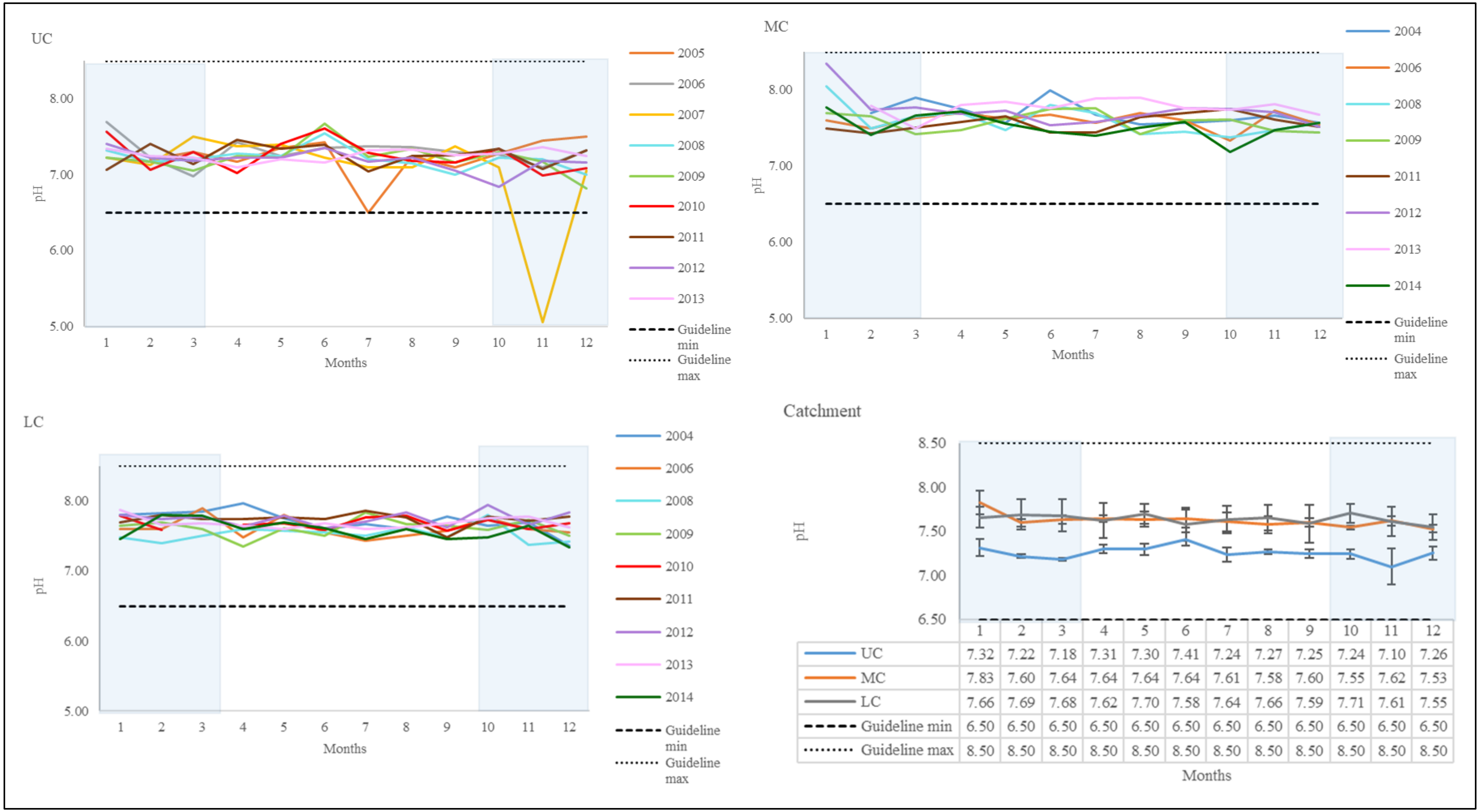
The mean monthly turbidity levels indicate that there is variation within the catchment and across the months of year. The error bars reflected in values indicate there is considerable variation in recorded turbidity values for each month (for example, values ranged from 5 NTU to 500 NTU at a single site). More concerning is that for some months turbidity values were within the acceptable arrange for recreational (5 NTU) use, however, these periods are followed by significantly higher values in preceding months within the same year. These exponential variations can't be explained through seasonal or flow differences. This alludes to specific activities occurring along the catchment. The WWTWs located primarily in the mid catchment have experienced multiple system failures and leaks over the years (Carnie, 2008); this could explain the large-scale variability in turbidity levels.

Turbidity levels in the catchment exceeded the international WHO guideline limits of 5 NTU, as well as the SAWQG-DU of 1 NTU. Although not an inherent danger to human health the available particles provide a surface area for parasites and microbial contaminants upon which to settle (WHO, 2011; Yang *et al*., 2015). Contact with the water would increase the risk of illness and the possibility of infection (DWAF, 1996a; WHO, 2011). Additionally, high turbidity levels would have resulted in cloudy or muddy water and limit the ability of sunlight to penetrate the water (Prabhu, 2019). This would inhibit photosynthesis, reduce available oxygen (leading to eutrophication), and impair visibility and ability to feed among aquatic species (turbid waters decrease the ability to detect prey or sense a predator's presence) (Henley *et al.*, 2000; Leahy *et al*., 2011; Prabhu, 2019).

4.4.2. pH

The ideal pH for drinking water is between 6.5 and 8.5, at this range there are no significant effects on taste, health or appearance and metal ions are less likely to dissolve (DWAF, 1996a; WHO, 2011). The recommended pH levels for the well-being of aquatic organisms is between 6 and 8 and shouldn't differ from original values by more than 0.5 of a pH unit or 5% (DWAF, 1996c).

Results show slight variation in pH across the catchment and across the years with the exception of one event in November 2007 that recorded a pH of 5 (Figure 4.7). The pH levels in the UC remained within the upper and lower limits of the SAWQG. The pH in the MC remained in the ideal range over the 12 months for years 2004 to 2014. Similar trends were noted for the LC across the years. A student's T-test indicated that the distribution of pH in the catchment did not significantly different over the observed period (p= 0.357). As such, it is less likely that pH would have any adverse effects on the quality, taste and odour of the water and, on river ecology. It is also less likely for excess metal ions to dissolve in the water (WHO, 2011).



	1	2	3	4	5	6	7	8	9	10	11	12
UC	7.32	7.22	7.18	7.31	7.30	7.41	7.24	7.27	7.25	7.24	7.10	7.26
MC	7.83	7.60	7.64	7.64	7.64	7.64	7.61	7.58	7.60	7.55	7.62	7.53
LC	7.66	7.69	7.68	7.62	7.70	7.58	7.64	7.66	7.59	7.71	7.61	7.55
Guideline min	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50	6.50
Guideline max	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50	8.50

Figure 4.7: Mean monthly pH levels (2004-2014) within segments of the Umhlatuzana Catchment

4.4.3. E. coli

The WHO recommends that any water intended for drinking have no detectable amounts of *E. coli* in a 100 ml sample (2011). The SAWQG stipulates that the maximum amount of *E. coli* detectable in a water sample should not be more than 0 counts/100ml for domestic use and 130 counts/100ml for recreational activities (DWAF, 1996a; DWAF, 1996b). Samples that exceed the guideline limits are considered to hold significant risk to those who utilise it for any purpose (DWAF, 1996a).

E. coli levels discussed below have been measured in Colony Forming Units (CFU) by eThekwini Municipality and are universally represented as CFU per millilitre. Colony Forming Units are the number of colonies growing on a cultured agar plate. A solution of the original sample is plated on agar and incubated before counting the individual colonies that are growing (Brugger *et al.*, 2012). The colony may be derived from a single viable cell or from multiple viable cells; as such it is argued that CFU are not a true representation of all cells dead or alive in the original sample (Brugger *et al*., 2012; Chiang *et al*., 2014). However, as colonies are a collection of bacteria, it may be assumed that a single colony may exceed individual counts.

Figure 4.8 displays the monthly distribution of *E. coli* measured in the Umhlatuzana catchment for the 11-year period. The levels of *E. coli* measured in the UC were distributed between 1 000 and 10 000 CFU /100 ml with little variance in distribution over 12 months. The distribution of *E. coli* in the MC differed as samples which exceeded 100 000 CFU/100ml were observed mostly between the January and June in 2008 and 2009. The observed levels of *E. coli* in the LC were dispersed between 100 and 100 000 CFU/100ml. Spikes have occurred throughout the catchment and across the observed timeframe, predominantly peaking in the rainy season. The large standard error values indicate a large-scale variation.

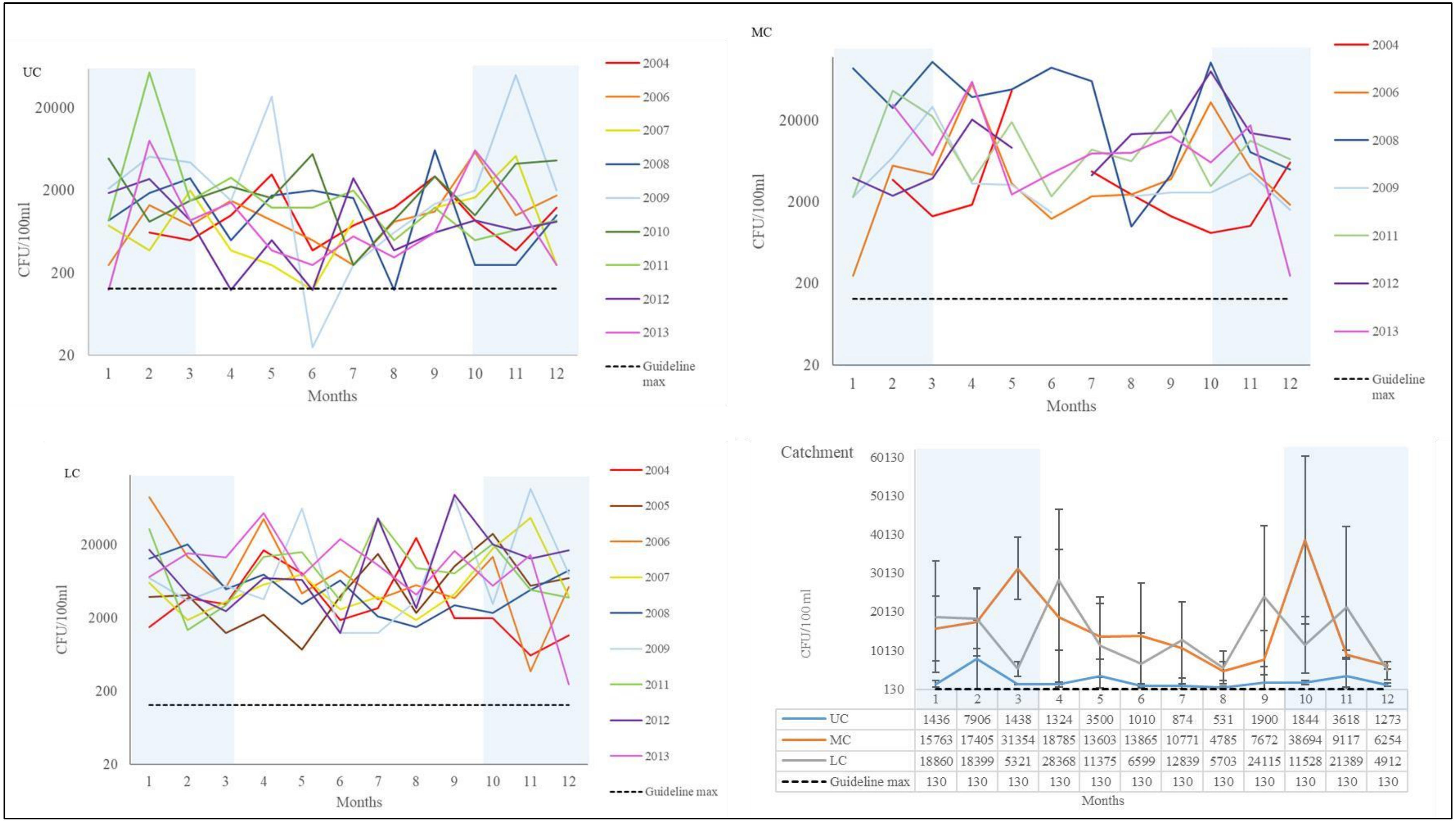


Figure 4.8: Mean monthly *E. coli* levels (2004-2014) within segments of the Umhlatuzana Catchment

Overall, *E. coli* levels in the UC (r= 0.100, *p*= 0.017) and MC (r= 0.160, *p*= 0.0001) increased significantly from 2004 to 2014. There were no significant differences (r= 0.48, *p*= 0.255) in *E. coli* levels in the LC for the period 2004 to 2014. The WHO (2011) recommend that the optimum level of *E. coli* in water should be zero, whilst DWAF (1996a) recommends a maximum of 0 CFU/100 ml for domestic use and 130 CFU/100 ml for recreational use (DWAF, 1996b). These results are alarming and highlight that the water from the Umhlatuzana River is not fit for domestic or recreational use. More concerning is the degree to which *E. coli* levels deviated from what is acceptable, where some values exceed 100 000CFU/100ml.

The levels of *E. coli* for the 11-year period were far above the levels identified as safe by DWAF (1996a) and WHO (2011). The presence of *E. coli* in river water is threat to public health if used for either domestic or recreational activities. The *E. coli* levels in the river increase the risk of domestic users contracting water-related diseases such as gastroenteritis, resulting in nausea, diarrhoea and dehydration (Zhang, 2012). The presence of *E. coli* may increase the risk of contracting Bilharzia (Olveda *et al*., 2014). Contraction of the parasite may occur when used for recreational activities, or other activities such as for religious reasons (Hinz *et al.*, 2017). The *E. coli* bacterium may also pose risks to the biodiversity of the Umhlatuzana River. The high count of bacterium indicates an increased pressure on DO availability in the river, decreasing oxygen availability would result in the endangerment of aerobic organisms, including fish (Ibanez *et al*., 2007; McEvoy *et al*., 1996).

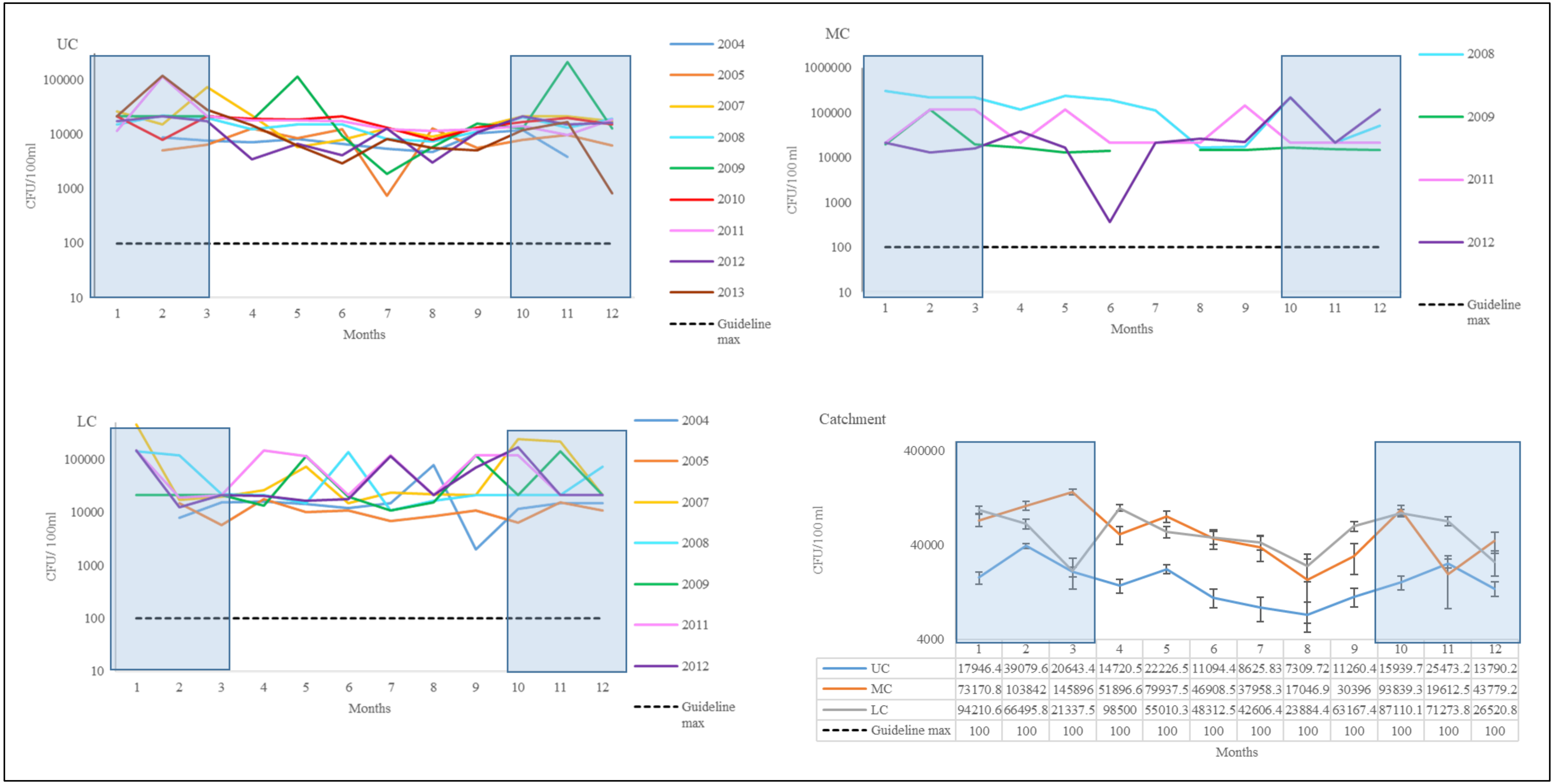
In addition, the severely escalating *E. coli* levels across many months and over many years highlight poor management of the catchment and water quality. Efforts to control the surge in *E. coli* (acknowledging that these levels are a serious threat to human and environmental health), would have resulted in marked decreases for at least some of the months in the year. However, results show uncontrolled oscillations in *E. coli* alluding to limited to no intervention by local government or environmental protection organisations. If left unchecked, the alarming levels could result in irreversible environmental degradation and a major health issue to local communities. The latter is a concern since there are a number of informal settlements (generally housing the most vulnerable groups) along the catchment.

4.4.4. *T. coli*

T. coli is a heterogeneous group of bacteria often used to test the hygienic quality of water and includes bacteria such as *Escherichia*, as well as coliforms which may not be faecal in origin (WHO, 2011). The presence of these bacteria may indicate that water has been inadequately treated and that disease-causing pathogens may be present as well (DWAF, 1996a). Similarly, eThekwini measures *T. coli* by filtering a solution of the sample (10 ml of the original sample diluted into 90 ml sterile deionised water) through a membrane and counting the resultant colonies. As such, *T. coli* is measured as the number of colonies per a 100 ml sample of water, counted after 24 hours (WHO, 2011).

Figure 4.9 displays the monthly distribution of *T. coli* measured in the Umhlatuzana catchment for 11 years. The *T. coli* in the UC measured between 1 000 and 100 000 CFU /100 ml and was lowest between June and October which can be considered the dry season. In the MC differed as samples which exceeded 100 000 CFU/100ml were observed mostly between January and June in 2008 and 2011. The observed levels of *T. coli* in the LC were dispersed between 1 000 and 100 000 CFU/100ml and mostly consists of peaks throughout the year, particularly in 2011 and 2012.

The *T. coli* levels exceed the parameters (5 CFU/100ml) of the SAWQG-DU and as such have a significant risk of transmitting water related diseases if utilised for domestic or recreational activities (DWAF, 1996a; DWAF, 1996b; WHO, 2011). *Total coliforms* is the presence of all microbial coliforms, which may not be pathogenic or faecal in nature, but rather indicates the hygienic qualities of water (DWAF, 1996a). The *T. coli* levels presented above indicate the presence of *T. coli* above acceptable levels stipulated by WHO (2011) and DWAF (1996a). At these levels, there is a greater probability of the presence of pathogenic bacteria, including bacteria faecal in origin (DWAF, 1996a). This would result in water-users being at an increased risk of contracting water-related diseases (WHO, 2011).



Months	1	2	3	4	5	6	7	8	9	10	11	12
UC	17946.4	39079.6	20643.4	14720.5	22226.5	11094.4	8625.83	7309.72	11260.4	15939.7	25473.2	13790.2
MC	73170.8	103842	145896	51896.6	79937.5	46908.5	37958.3	17046.9	30396	93839.3	19612.5	43779.2
LC	94210.6	66495.8	21337.5	98500	55010.3	48312.5	42606.4	23884.4	63167.4	87110.1	71273.8	26520.8
Guideline max	100	100	100	100	100	100	100	100	100	100	100	100

Figure 4.9: Mean monthly *T. coli* levels (2004-2014) within segments of the Umhlatuzana Catchment

The prevalence of bacteria in the upper waterway may influence the availability of DO in the system (McEvoy *et al*., 1996). The increased oxygen demand is likely to alter the ecology of the river thereby impacting biodiversity as depleted oxygen results in the death of riparian fauna (Ibanez *et al*., 2007). The elevated *E. coli* and *T. coli* levels indicate pollutants from a sewage source are entering the river and are causes for concern regarding human health. The use of this river water for domestic activities without treatment is likely to result in gastroenteritis, cholera and salmonellosis (DWAF, 1996). Furthermore, the use of this source for recreational activities, or contact with the source increases the risk of users contracting bilharzia, in which has infected an estimated 4 million South Africans (Magaisa *et al.,* 2015).

The elevated levels of *T. coli* and *E. coli* indicate pollution from sewage sources, likely to be the result of malfunctioning WWTW. This was evidenced by a sewage leak from the Queensburgh WWTW occurring in December 2007 (Carnie, 2008), contributing to the high *E. coli* counts in January 2008. The effect of the spill is evident in the elevated *E. coli* and *T. coli* levels of the following year, as effluent spills remain in the system for some time (Attwood and Boomgaard, 2014). The *E. coli* levels present in the Umhlatuzana river are of particular concern for the informal households within the catchment as well as the 1-kilometre buffer. As informal settlements characteristically lack access to piped water and sanitation, the *E. coli* levels increase the health risks to households that may utilise the river as a source of water (Boehm *et al*., 2009; Marshall *et al.*, 2009).

4.4.5. RWQI

The RWQI is a scale used by the eThekwini Municipality in order to rate the quality of the various rivers within their boundary. Adapted from the water quality index (WQI), the RWQI is based on *E. coli* and PV4 (permanganate value) levels of monthly water samples. Based on observed measured of water quality, the region is given a score ranging from 1 to 4, with 1 being characterised as ideal and 4 being critical. The combination of the water quality results in the UC; provide insight as to why this portion of the river is rated as critical or poor on the RWQI throughout the observation period. The eThekwini Municipality began using this scale on a monthly basis in 2006; therefore, this study only reports values from this period. This index is pertinent to this study as it provides insight on the municipal classification of rivers, particularly those such as the Umhlatuzana that service a myriad of uses and users.

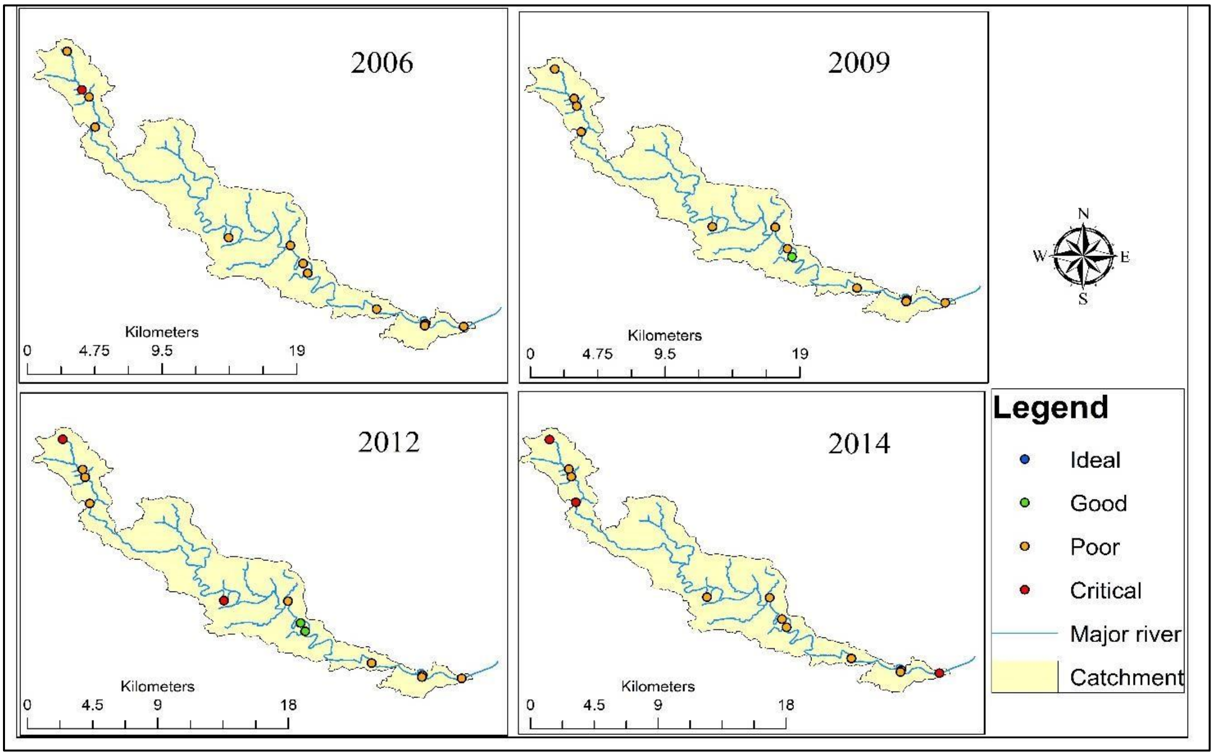
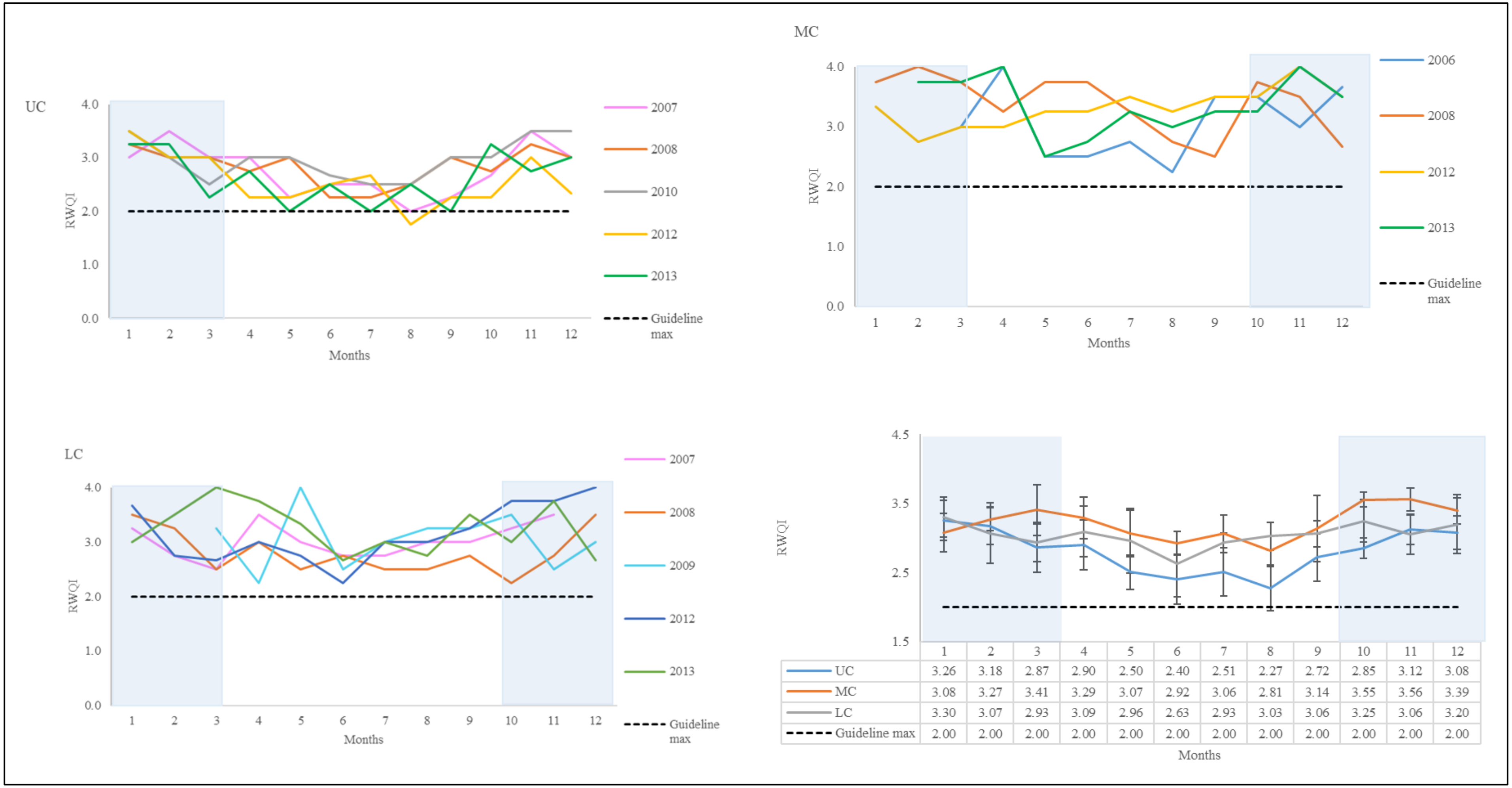


Figure 4.10: RWQI at sample sites in the catchment of the Umhlatuzana River a 9-year period

Results show that RWQI values ranged between 2 and 3.5 across all sites over the 9-year period. In the UC, RWQI scores were better in the dry season ranging between good and poor (4^{th} to 9^{th} month) in comparison to the remainder of the year (ranging between poor and critical). The RWQI for the MC ranged between good and critical, and in the LC ranges between good and poor in the dry months (between April and September) and between poor and critical for the remainder of the year. Overall, the RWQI indicates that the river water hovers between poor and critical for most of the year and is best in the UC. This classification of poor water quality means that remediation and restoration in the catchment will not be prioritised, only rivers that are classified as critical are prioritised for intervention.



	1	2	3	4	5	6	7	8	9	10	11	12
UC	3.26	3.18	2.87	2.90	2.50	2.40	2.51	2.27	2.72	2.85	3.12	3.08
MC	3.08	3.27	3.41	3.29	3.07	2.92	3.06	2.81	3.14	3.55	3.56	3.39
LC	3.30	3.07	2.93	3.09	2.96	2.63	2.93	3.03	3.06	3.25	3.06	3.20
Guideline max	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00

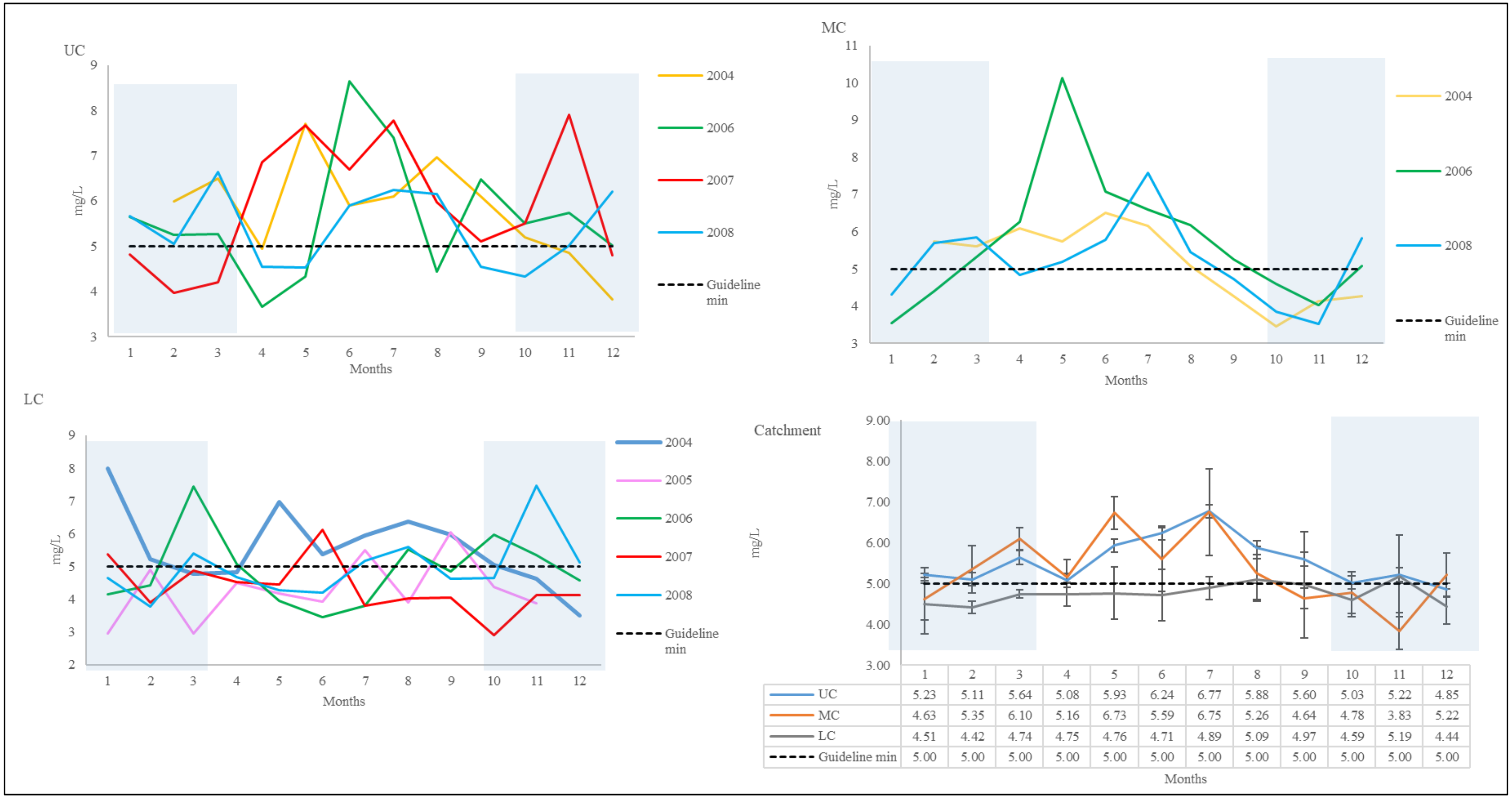
Figure 4.11: Mean monthly RWQI levels (2004-2014) within segments of the Umhlatuzana Catchment

In essence, it may be concluded that the quality of water in the Umhlatuzana River, according to the index utilised by the eThekwini Municipality, ranged between poor and critical over the observed period. Moreover, the poor and critical indicators in the lower catchment indicate the release of inferior water into Bayhead Canal, and eventually Durban Harbour. The persistent poor condition of the river highlights the need for an effective management system. This system can be considered as reactive rather than proactive, allowing rivers to deteriorate to critical levels at the detriment of environmental and human health.

4.4.6. DO

The amount of oxygen dissolved in a water sample depends on various factors such as temperature, dissolved salts, atmospheric pressure as well as suspended matter and living species (Ibanez *et al.*, 2007). Dissolved Oxygen indirectly indicates the presence of pollutants in water and is a reliable indicator of water quality (Jackson *et al.*, 1989). Most species of fish require a DO concentration of 5 mg/L and although it does not have a direct impact on human health, it is used as an indicator of environmental health for this study (McEvoy *et al.*, 1996). Data obtained from the eThekwini municipality shows that DO levels were only tested from 2004 to 2009 and as such, the periods illustrated in the following figures spans 6 years.

In the UC, total DO was primarily above the guideline minimum, and was greatest in May 2006, a steep incline from the previous month. The lowest DO levels were recorded between December and April for the observed years. Overall, the range varied between 3 and 9mg/L, with the lowest levels measured in the rainy seasons. A steady decline in DO levels in the MC is evident between August and September leading into the rainy season, below the 5mg/L guideline minimum. Similar to the upper catchment, the highest DO levels were in May 2006, preceded by low levels of DO. The DO in the LC varied greatly over 12 months with most observations occurring below the guideline minimum. When observing the trends over 12 months in the catchment, the dry season had higher levels of DO that the rainy season. When comparing the UC, MC and LC, DO levels are predominantly lowest in the LC. The error bars indicate the high variability of the data for each month in the catchment.



	1	2	3	4	5	6	7	8	9	10	11	12
UC	5.23	5.11	5.64	5.08	5.93	6.24	6.77	5.88	5.60	5.03	5.22	4.85
MC	4.63	5.35	6.10	5.16	6.73	5.59	6.75	5.26	4.64	4.78	3.83	5.22
LC	4.51	4.42	4.74	4.75	4.76	4.71	4.89	5.09	4.97	4.59	5.19	4.44
Guideline min	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

Figure 4.12: **Mean monthly *DO* levels (2004-2008) within segments of the Umhlatuzana Catchment**

The low levels of DO, particularly in LC where the industrial activities are concentrated, below the accepted level of 5 mg/L, indicates possible organic or thermal pollution as well as the possible endangerment of aerobic organisms (McEvoy *et al*., 1996; Ibanez *et al*., 2007). The decline in DO may be attributed to the increase in turbidity levels during the same period, the insufficient penetration of sunlight results in a reduction of oxygen production by riparian flora (Henley *et al*., 2000). The presence of bacteria and the decomposition of sewage due to the high levels of *E. coli* may have reduced the DO levels in the MC and LC in January 2008, increasing the likelihood of death for river organisms. This effluent spill is believed to be the cause of fish deaths in the Durban Harbour seen late December 2007 (Carnie, 2007). As highlighted by Martinelli and Filoso (2008), surface runoff is likely to be accompanied by excess nutrients from farming activities such as the sugar cane plantations present in the catchment. The presence of a WWTW outfall increases the likelihood of a sewage spill. This WWTW outfall, combined with the presence of livestock and septic tanks in the upper catchment area may account for the presence of *E. coli* in the upper waterway (Figure 4.8).

4.4.7. TDS

Salinity of freshwater ranges between 0 and 1 000 mg/L. Increasing salinity in freshwater is a serious environmental challenge as it has a great effect on a river's ecology and biodiversity (James *et al*., 2003; Kefford *et al*., 2004; Sharma, 2008). Increases in biological and chemical oxygen demand occur when there are high levels of dissolved solids in a water system, resulting in the depletion of dissolved oxygen in aquatic systems (Jonnalagadda and Mhere, 2001). Increasing salinity levels would result in the river water becoming brackish, endangering the well-being of freshwater organisms and the rivers biodiversity (Sharma, 2008).

Levels of TDS (Figure 4.14) in the UC generally increased between May and June in the year with peaks in June and November in 2007 and in March in 2008. Statistical analysis indicates that TDS levels in the UC decreased significantly from 2004 to 2014 ($r= -0.14$; $p= 0.003$). The MC had several peaks of TDS between May and October; the greatest peak was in January of 2014. Similar to the UC, several peaks in TDS occurred between June and September. As in the MC, there was a peak of 1 166.75 mg/R in TDS levels in February of 2014 in the LC. Other peaks in the LC occurred in June of 2009 2010, and January of 2008. The error bars indicate the high levels of variability of the data for each month in the catchment. Throughout the period, levels of TDS did not exceed the guideline limits and remained within freshwater levels.

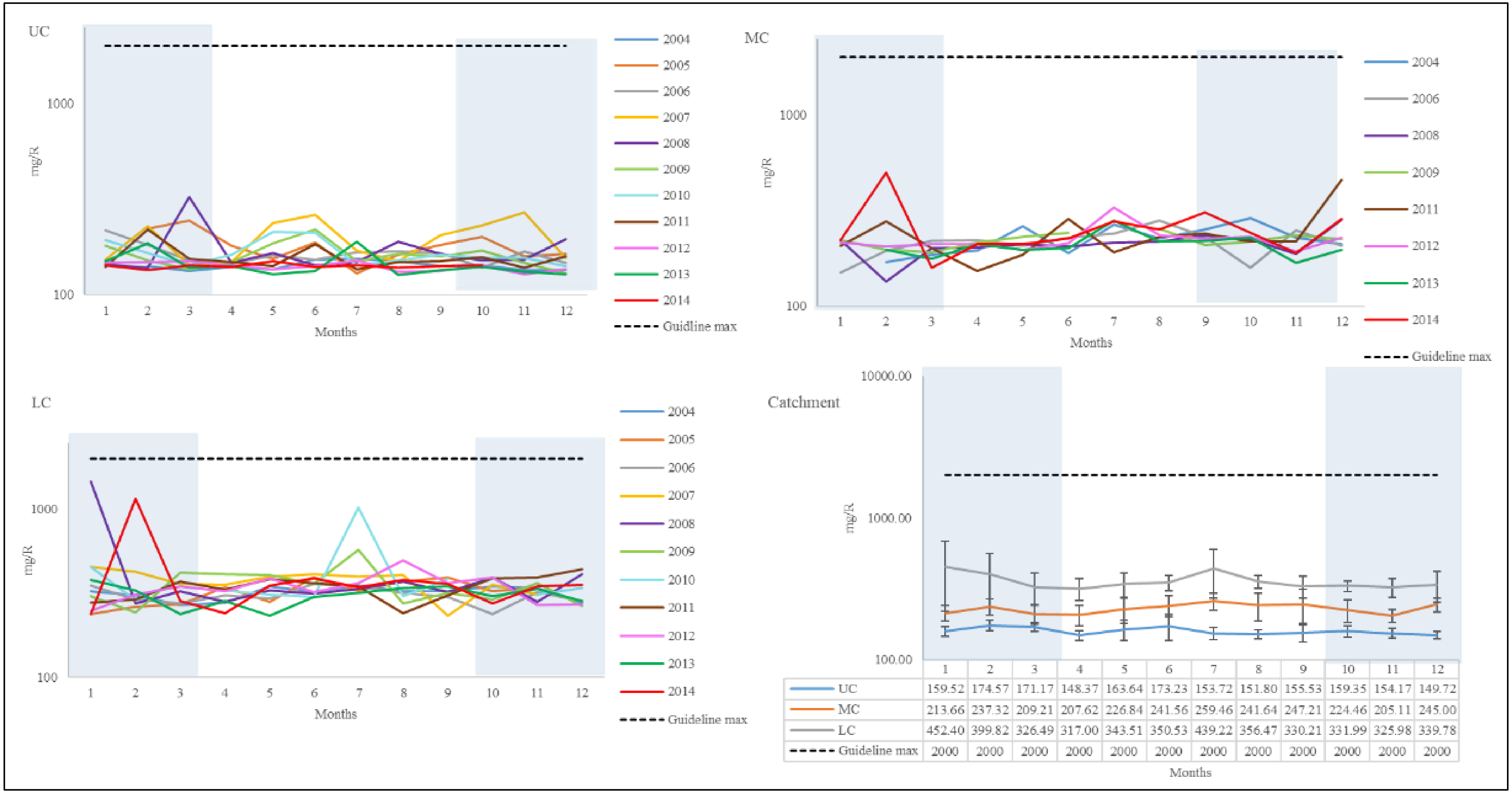


Figure 4.13: Mean monthly TDS levels (2004-2014) within segments of the Umhlatuzana Catchment

4.4.8. Colour

Water colour is commonly used as a qualitative indicator for water quality and river health. Colour can also be diagnostic is highlighting a number of characteristics such as turbidity, organic matter or the presence of minerals. Additionally, impacts on water colour may also be due to human activities such as industrial dye houses.

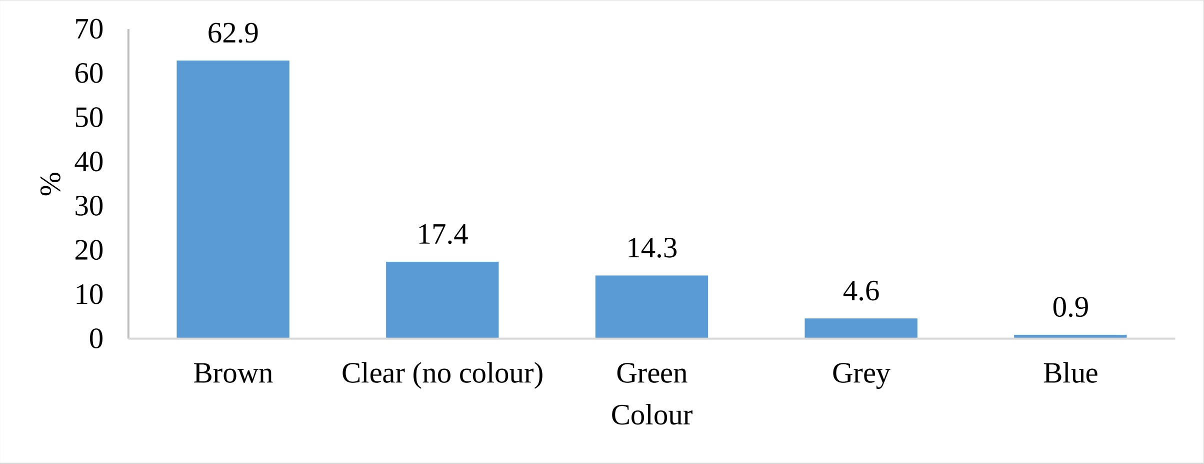


Figure 4.14: Characterisation of river water colour (n=350, in %)

Site observations found that the river water ranged from clear in shallow slow-moving water, to brown and turbid in deep, fast flowing waters. Additionally, the river water was noted to be grey in residential areas with a soap like odour. Respondents characterised the river water has having a brown colour (62.9%) This is supported by the increased levels of turbidity shown in figure 4.14, which may have resulted in the water appearing brown and muddy. Several respondents (17.4%) indicated that the observed water had no colour and was clear enough to see the riverbed. Fewer respondents, 14.3% indicated that the water typically appeared to be green in colour and a minority of the respondents (4.6%) indicated that they had observed the water to be grey, which maybe because of domestic wastewater disposed into the river. Evidently, respondent accounts of water colour varied in relation to their location along the catchment. Respondents mainly from the UC perceived clear waters, while respondents located along the MC highlighted a brown colour. Respondent perceptions of water colour in the LC varied between green and grey.

The perception of colour may be explained by neighbouring land use type. For example, the MC region showed intense settlements, intensive agricultural and industrial activities possibly resulting in increased surface-runoff hence more turbid waters. Similarly, the UC showed higher coverage of vegetation and therefore prevalence of clear/ colourless waters. These results are further corroborated by observations described above.

4.4.9. Odour

Odour has also been used as a qualitative indicator of water quality and river health. River odour could vary from fishy to rotten eggs or excrement and may be due to the presence of organic material, hydrogen sulphide or contamination of water by sewage.

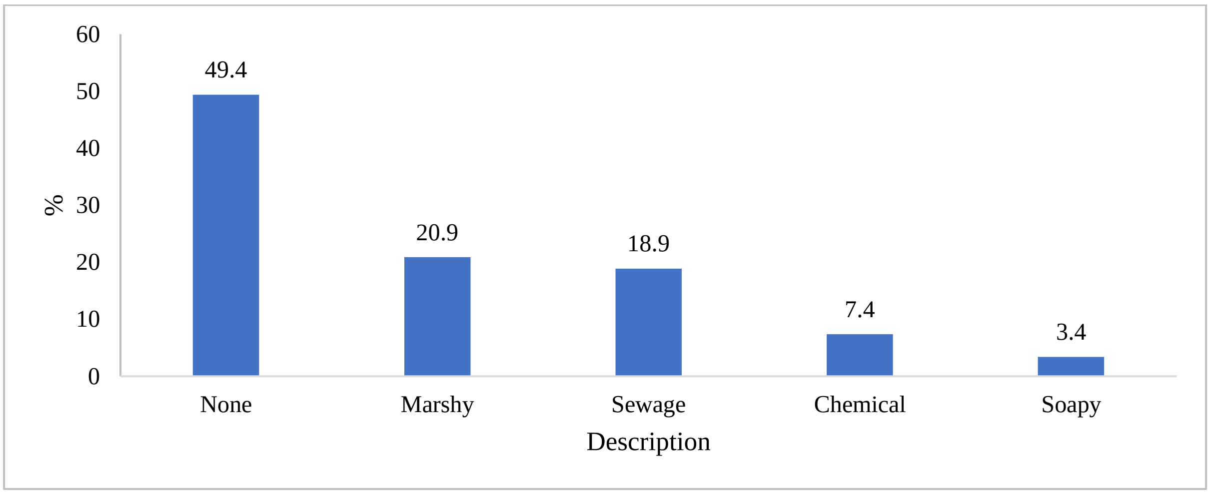


Figure 4.15: Characterisation of river water odour (n=350, in %)

During field observations, the river water odour was noted. Several sites had no noticeable odour, sites with slow moving water and increased vegetation had a low to moderate musty odour usually associated with water bodies. As previously noted, a soapy odour was detected in sections of the river where the water appeared grey.

In describing the characteristics of the river water, respondents were required to describe the general odour of the river. A noteworthy 49.4% of respondents indicated that the water did not have any perceivable odour, whilst 20.9% of respondents indicated that the water had a marshy odour. This may be described as the odour characteristic of natural stagnant water bodies surrounded by vegetation. Fewer respondents (18.9%) indicated that the river water had a sewage-like odour, and 7.4% of respondents indicated they noted a chemical odour. Just over 3% of respondents indicated that the river water had a soap-like odour. While much of the perceptions of odour align with natural river systems, the chemical and sewage like odours are cause for concern. However, these findings are unsurprising since earlier results show alarming levels of *E coli* and *T. coli* in the MC and UC regions.

These results highlight the value of qualitative indicators as early warning mechanism. Moreover, the use of colour and odour as indicators of river health can offer unique opportunities for the monitoring of river systems under resource limitations. In this regard, citizens can contribute to monitoring of natural environments by using the simple indicators that require very little training and resources. In cases such as the Umhlatuzana catchment that covers an extensive area having look outposts for volunteers could ease the burden of monitoring on local government. This always creates a sense of custodianship and awareness among surrounding communities.

The results of the water quality parameters allude to the influence of land use activities in the catchment. Turbidity levels were above acceptable limits and increased over the observed period in the catchment. These changes and exponential variations are not due to seasonal or flow differences and may be attributed to the surrounding land use activities. In the UC the presence and increase in agricultural activities is noted in literature contribute to the sediment load of nearby waterbodies (Martinelli and Filoso, 2008; Nyenje *et al*., 2010). Additionally, the presence of industrial activities and trade effluent outlets in the MC and LC may explain the large-scale variability and the increase in turbidity in these areas of the catchment (Malmqvist and Rundle, 2002; Yang *et al*., 2015).

Levels of *E. coli* and *T. coli* increased and was highest in the MC and LC over the observed period. The uncontrollable oscillations may be attributed to the land uses present in these areas of the catchment. The concentration of informal urban settlements in the MC and LC is typically underserviced and as indicated in literature, most likely to have residents use the river to satisfy their water and sanitation needs (Bond, 2014; Okurut *et al*., 2014). Additionally, the presence of WWTW outfalls along the river in the MC and LC increases the likelihood of malfunctioning systems discharging untreated sewage into the river system. The malfunction at the Queensburgh WWTW in December 2007 was noted as the cause for spikes in *E. coli* and *T. coli* levels for that month and subsequent months in 2008 (Carnie, 2008; Attwood and Boomgaard, 2014).

The dynamics observed in the catchment between land use and the river system are underpinned by the goals of socio-hydrology as discussed in chapter 2. The impacts of land use on water quality as highlighted in the discussions of *E. coli* and *T. coli* parameters in relation to activities in the MC and LC such as WWTW outfalls and informal urban settlements illustrate the importance of incorporating both aspects in understanding vulnerability in the catchment community. Moreover, place perspectives as in Geographies of health provide insight into the influences of the surrounding environment on community health. These aspects are important to consider when examining household use of river water in the following section.

4.5. Utilisation and household survey respondents' perceptions of land use and water quality in the Umhlatuzana catchment

The survey explored household interactions, utilisation and perceptions of the river. The results below are discussed in relation to land use and water quality assessments presented earlier. Survey data revealed that 14.6% of respondents used water from the river for domestic purposes. The diverse income ranges of respondents illustrate the heterogeneous nature of the peri-urban community, as well as the income disparities in South Africa. In these communities, households with greater income have better access to resources and infrastructure in comparison to the lower income households (Vemerink *et al*., 2011). According to Bond (2014), this is unsurprising since households switch between sources due to their limited ability to pay for the service. This is concerning since these households were primarily from the informal settlements. The risks of consuming untreated poor quality water may present serious health risks since many of these individuals may be unable to access health care. As a result, the lower income households are more likely to use the nearby river body to meet their daily water needs (Dungumaro, 2007; Doria, 2010). Of the households that used water from the river for domestic activities, the majority of households that used water from the river did not treat it before use (70.6%) and forwarded reasons for this (Table 4.11).

Table 4.11: Reason for not treating water before use (n=36, in %; Multiple responses permitted)

Reason	%
Lack the required equipment	10.3
Lack the time	2.6
Do not think it is necessary	87.2

A noteworthy 70.6% of households that did not treat the river water before use indicated that it was as they did not think it was necessary to do so (figure 4.11). Following this, 10.3% of households specified that they lacked the equipment that is required to treat the water and 2.6% indicated that they lack the time to do so. These results are alarming given the high levels of *E* *coli* and *T coli* within the river. More importantly, the use of untreated water from the river poses a series of health risks to the surrounding communities. Households that do not treat the river water before use are at increased risk of contracting water borne illnesses, affecting their health and well-being (Okurut *et al.*, 2014).

Of the respondents that treated the water before use (29.4%), the most common method was to boil it (66.7%), the other method used was to pour bleach into the water before it was used (46.7%). When drinking the water, the majority of households used bleach to make it suitable. Bleach is a known to kill bacteria in water, however too much may have an adverse effect on health due to its corrosive nature.

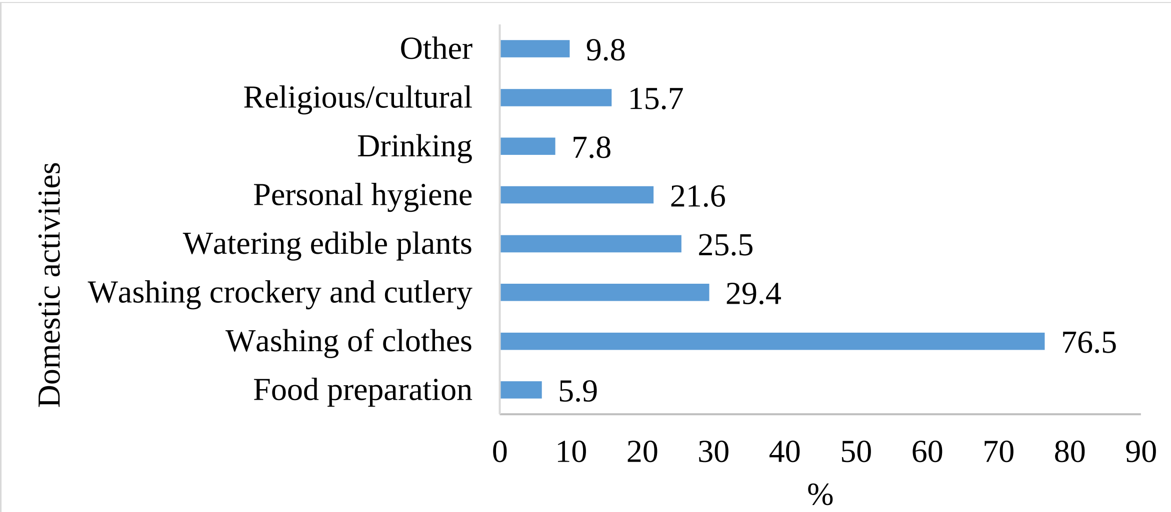


Figure 4.16: Household domestic activities using Umhlatuzana river water (n=51, in %; Multiple responses permitted)

Households that used water from the Umhlatuzana River shared the specific uses (Figure 4.16). Most notably, respondents used the river water for laundry purposes (76.5%), whilst fewer used the water for washing household dishes (29.4%). Others used the river to irrigate edible plants (25.5%) and for personal hygiene (21.6%). The latter included brushing of teeth and washing of their hair and bodies. A minority used the water for religious or cultural activities (15.7%), drinking (7.8%) and food preparation (5.9%). Responses revealed that households also utilise the river water for other activities that includes flushing toilets, washing of cars, swimming, watering livestock and producing cement blocks. Observational visits confirmed the presence of block making activities alongside the river (pictured in image 4.1).

Image 4.1: Block manufacturing activities alongside the Umhlatuzana River in Tshelimnyama in the MC

The majority of respondents (76.5%) indicated that they used the water for laundry purposes. Additionally, the activities listed are essential domestic activities, the completion of these activities using river water indicates that the river is used for basic needs. This is alarming given the *E. coli* and *T. coli* levels presented earlier. Activities such as drinking, food preparation and watering of edible plants indicates the ingestion of the river water, resulting in a direct threat to household health. Cross tabulations indicated that water used for drinking was treated before used by boiling or adding bleach. According to Rosa *et al*. (2016), the treatment of water before ingestion reduces the risk of illness usually associated with *E. coli*. However, it should be noted that treatment of contaminated water is a complex process dependent on volume and type of detergent, period of treatment and storage conditions. In this regard, this study does propose a note of caution in assuming the safety of water consumed by respondents even though they indicated some level of treatment before consumption.

Other activities such as personal hygiene, religious/cultural activities and the washing of crockery, cutlery and clothes is unhygienic due to the *E. coli* levels observed and makes the users vulnerable to dermal issues and water-based illnesses such as bilharzia. This study reveals that respondents are at risk and extremely vulnerable to illnesses such as cholera and gastrointestinal distress. These illnesses make it difficult to participate in family life and attend work or school (Odundo *et al*., 2018).

Table 4.12: Frequency of use of the Umhlatuzana River (n=51 in %; yes responses only)

Activity	Daily (%)	Weekly (%)	Monthly (%)
Food preparation	2	-	3.9
Washing clothes	17.6	41.2	17.6
Washing crockery and cutlery	21.6	3.9	3.9
Watering edible plants	13.7	11.8	-
Personal hygiene	17.6	-	3.9
Drinking	2	2	3.9
Religious/ cultural	7.8	3.9	3.9
Other*	2	2	5.9

*other activities included washing of cars, production of cement blocks, swimming and watering of livestock

The survey also probed on frequency and duration of use (table 4.12). Surveyed households indicated that river water was used daily to wash crockery and cutlery (21.6%), wash clothes (17.6%), for sanitation (17.6%), and to water edible plants (13.7%). Additionally, households that utilise river water on a daily basis indicated it was used for food preparation (2%) and drinking (2%). Other activities such as washing of cars, watering livestock, swimming and the production of cement blocks mostly occurred monthly.

The frequency of utilisation suggests that there is limited availability of piped water to households. More concerning, it that these households face elevated health risks given their frequent exposure and consumption to contaminated water. The frequent use of the river water increases exposure to illnesses and water-related diseases such as bilharzia. This is of particular concern as *E. coli* and *T. coli* results have increased over the observed period, surpassing local and international thresholds for domestic and recreational use.

Table 4.13: Duration of use of river water (n=51, in %)

Timeframe	%
<20 minutes	17.6
20-60 minutes	35.3
>60 minutes	47.1

Respondents from sampled households indicated the duration of each activity when using water from the Umhlatuzana River (Table 4.13). The majority of households (47.1%) were in contact with the river water for more than 60 minutes at a time. A further 35.3% of households were in contact with the water for 20 to 60 minutes and a minority 17.6% used the water for less than 20 minutes at a time. The duration of the domestic activity is an indication of the amount of time households are in contact with the river water. Greater exposure to contaminated waters increases the health risks to all users. Female household members are particularly vulnerable as they primarily perform the activities that require greater time (washing of clothes and crockery and cutlery) on a daily to weekly basis.

Table 4.14: Household members utilising the river (n=51, in %)

Household member	%
Everybody	56.8
Females mainly	27.5
Males mainly	15.7

In figure 4.14, the majority of households indicated that several members of the household (56.8%) utilised the river for various domestic activities. Thereafter in 27.5% of households mainly females utilised the river, additionally 15.7% of households indicated that mainly male members utilised the river. In these households both men and were vulnerable to contracting illnesses, affecting their ability to provide for the household or take care of the household. Given the high levels of *E. coli* and *T. coli* it is concerning to see that all members of the household were at a higher risk of contamination due to contact with the river.

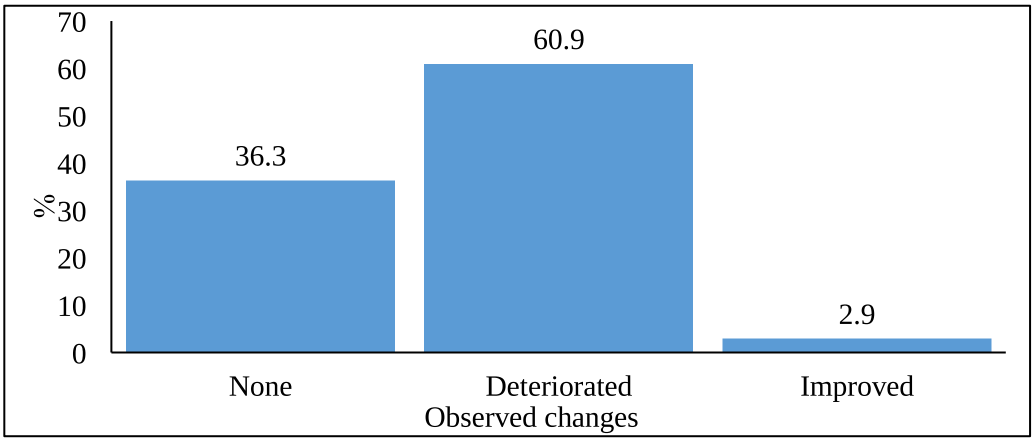


Figure 4.17: Perceived changes in water quality over 10 years (n=350, in %)

Respondents characterised the change in water quality that they have perceived over a 10-year period. A noteworthy 60.9% of respondents indicated that the river has deteriorated over the last 10 years, 36.3% noted no observable changes and 2.9% indicated an improvement in the water quality. Generally, respondent's perceptions closely align with observed changes in water quality. It is interesting to note that despite the perception that water quality had deteriorated over the years, certain respondents continued to use the river for basic needs. Additionally, households that resided in the area for longer periods were more likely to indicate a deterioration in the river water quality (Pearson chi-square test, $p = 0.019$).

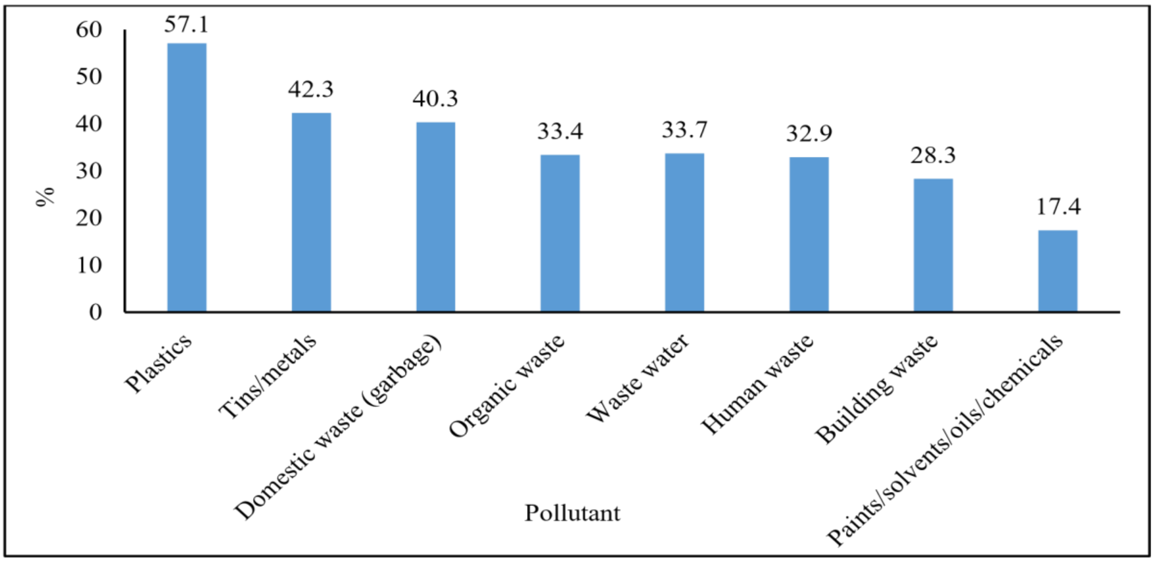


Figure 4.18: Observed pollution of Umhlatuzana River (n=350, in %; Multiple responses permitted)

Respondents indicated the types of waste they had observed being disposed into the river (Figure 4.18). A noteworthy 57.1% of respondents indicated that they had observed plastics being disposed into the river, a further 42.3% indicated that they had observed tins/ metals disposed into the river, and 40.3% indicated domestic waste, such as kitchen waste. Other wastes that had respondents had observed being disposed in the river included organic waste such as yard trimmings (33.4%), wastewater (33.7%) and human waste such as excreta and urine (32.9%). A minority of respondents indicated that they had observed building related waste (28.3%) and paints/solvents/ oils or chemicals (17.4%) being disposed in the river. Discarded waste was observed at each site and oil residue was noted on sandy banks of the river (image 4.2).

The results above may reflect the poor state of waste disposal in the catchment community. This may be due to poor or complete lack of waste management service that should be provided by the municipality. Given the socio-economic status of the surveyed households, they may not be capable of paying the fee related to waste management services.

Image 4.2: Evidence of oil residue and litter on the floodplain of the Umhlatuzana River

The disposal of human waste into the river increases *E. coli* and bacterial loads in the river, increasing the risk to users' health. Wastes such as chemicals, oils and organic/domestic waste may affect pH and DO levels of the river, making it unsuitable to support life or use as freshwater. The type of waste is of concern for estuarine and marine environments in the lower catchment areas. Anthropogenic litter, particularly litter, is well documented as detrimental to marine life, affecting nutrition, growth and reproduction in marine organisms (Paul-Pont *et al*., 2016; Provencher *et al*., 2017; Staffieri *et al*., 2018).

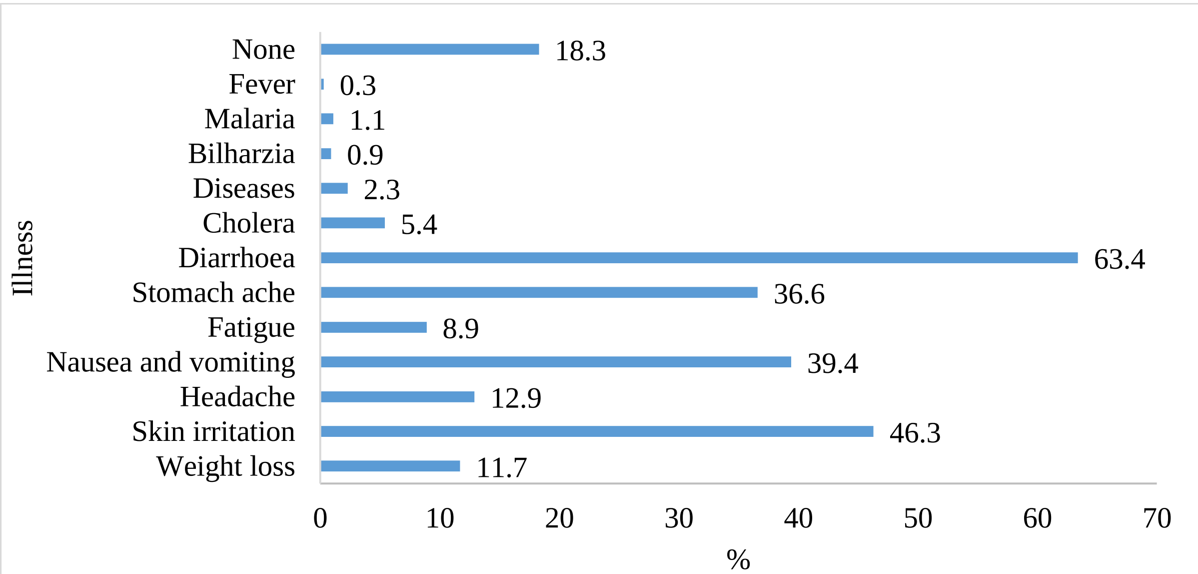


Figure 4.19: Perceptions of illnesses contractible through contact with Umhlatuzana River (n=350, in %; Multiple responses permitted)

Respondents from the sampled households indicated the types of illnesses they perceived one might contract if they are in contact with water from the Umhlatuzana River. A notable 63.4% of respondents indicated that one may contract diarrhoea and 46.3% highlighted skin irritations. Other illnesses perceived to be contractible through contact with the river water included nausea and vomiting (39.4%), stomach-ache (36.6%), headache (12.9%) and unintentional weight loss (11.7%). Fewer respondents indicated that contact with the water might result in fatigue (8.9%), cholera (5.4%) and other diseases such as cholera and bilharzia (2.3%). A minority of respondents also indicated that one might contract malaria (1.1%), bilharzia (0.9%) and a fever (0.3%) if in contact with the river water.

Respondents are knowledgeable about the basic health risks of drinking contaminated water as they identify symptoms of gastrointestinal distress. Other symptoms of contact with a polluted water source such as skin irritation was identified by many respondents and is likely to be through experience. Illnesses such as diarrhoea, nausea, vomiting and stomach aches are common indicators of gastro-intestinal distress often exhibited after consuming water containing *E. coli (*Matano *et al.*, 2013). Due to the absence of health data for this community, this research is unable to establish whether these perceptions were informed by experience or knowledge of experience of these symptoms. Furthermore, it is interesting to note that the most commonly perceived illnesses were also symptoms of gastro-intestinal infections and common symptoms of *E coli* and *T coli* contamination.

Table 4.15: Perceptions of most vulnerable members of the household (n=51, in %)

Household member	**%**
All	25.5
Children (0-16 years)	56.9
Elderly (65+)	3.9
None	13.7

Respondents from households who utilised the river water indicated the members of the households that they perceived to be most susceptible to illness (table 4.15). The majority of respondents (56.9%) indicated that children are most susceptible to contracting illnesses from the river water. A further 25.5% of respondents indicated that all household members are vulnerable, and 3.9% indicated the elderly (household members of 65) are vulnerable to water related illnesses. It is concerning to note that 13.7% of respondents indicated that no household members are vulnerable to water related illnesses from the River. This does highlight a general lack of awareness by respondents on the safety of the water they use. It is noteworthy to mention that that although women performed the majority of household activities using the river water, they are not considered particularly vulnerable. During the survey, many respondents indicated that children in the community can be seen playing in or near the river and could have higher levels of exposure than other household members. According to literature children, women, elderly and immuno-compromised individuals are particularly susceptible to waterborne infections and illnesses (Amenu *et al.*, 2014; Hynds *et al.*, 2014; Bala *et al.*, 2015).

Table 4.16: Level of agreement with statements relating to the water quality (n=350, in %) (1- Strongly disagree, 2- Disagree, 3- Neutral, 4- Agree, 5- Strongly agree)

Statement	1	2	3	4	5	Mean
The quality of the river has a direct impact on my well-being	14.9	19.1	14	31.4	20.6	2
The quality of the river has a direct impact on the well-being of my community	9.1	12.9	12	43.4	22.6	3
Water quality is an important issue to be addressed in the community	21.4	23.7	13.1	27.7	14	3
Children in the community must be taught about the importance of a clean river	2.3	1.4	4.3	43.7	48.3	3
The community is well informed/ understands the water quality in the Umhlatuzana River	26.6	2.6	19.1	23.1	18.6	4

In order to understand the household respondent's perception of the Umhlatuzana River water quality, respondents were requested to rate their level of agreement with the statements in Table 4.16. Just over 50% of respondents agreed that the quality of water of water in the river had a direct impact on their well-being, whilst 34% indicated the contrary. A noteworthy 66% of respondents perceived river water quality to have an impact on the well-being of the community. Fewer respondents (22%) indicated that they did not perceive the river water to affect the well-being of their community and 7.1% had a neutral response. Of the sampled households, 41.7% of respondents indicated that they perceived water quality to be an important issue to be addressed in the community. However, a higher proportion (45.1%) of respondents indicated that water is not an important issue in the community that should be addressed in the community. These contrasting viewpoints could also allude to the value people associate with this resource. A noteworthy 92% of respondents were in agreement that it is necessary to educate children in the community about the importance of a clean river and 3.7% indicated the opposite. A few respondents (2.6%) neither agreed nor disagreed with the statement. A notable 41.7% of respondents perceived the community to be well informed of the water quality of the Umhlatuzana River, and 29.2% of respondents indicated contrasting opinions.

The majority of households identify the river to be a vital part of their community that is important for their well-being and that of the community. Although the majority of households agree that children should be taught the importance of the river, they do not consider water quality to be an important issue that should be addressed in the community. This is surprising since more than half of respondents used the water for domestic purposes. This could be explained by the respondents' prioritisation of other needs and challenges. For example, access to infrastructure, housing and employment could be perceived as more urgent. Needs are often prioritised according to importance, from the responses to the statements above, it can be argued that awareness campaigns on the risk associated with using contaminated water is much needed within these communities. This is qualified by the fact they face alarming levels of risk due to deteriorating water quality.

Table 4.17: Level of agreement with statements relating to the land use change over 10 years (n=350, in %), (1- Strongly disagree, 2- Disagree, 3- Neutral, 4- Agree, 5- Strongly agree)

Statement	1	2	3	4	5	Mean
In the past 10 years there has been an increase in informal dwellings	16	19.7	17.1	23.4	23.7	4
In the past 10 years there has been an increase in industrial activities in the catchment	13.1	23.7	18.9	25.4	18.9	3
In the past 10 years there has been an increase in construction activities	9.4	20	18.5	34	18	3
In the past 10 years there has been a decrease in farming activities	13.7	18.6	26	24.9	16.9	3
In the past 10 years natural land has been cleared and replaced by residential, industrial and commercial development	10	13.1	23.4	27.4	26	3

In order to understand the household respondent's perceived changes of land use in the surrounding catchment, they were asked to rate their level of agreement with the statements in table 4.16. A noteworthy 47.1% of respondents agreed that there has been an increase in informal settlements in the last 10 years, in contrary 35.7% of respondents disagreed with this statement. Approximately 7% of respondents were neither in agreement of disagreement with this statement. Since the respondents resided in different zones along the catchment, these divergent perceptions can be expected. Land use maps show that the increases in informal settlements were in specific to the MC and UC portions of the catchment.

A relative majority (44.3%) of household respondents agreed with the statement that in the past 10 years there had been an increase in industrial activities in the catchment over 10 years, this may be as formal residences, particularly in the LC, is in close proximity to industrial activities. A minority (10%) of respondents had a neutral response to the. The majority of the respondents (52%) agreed with the statement that there was an increase in construction activities within the area over the past 10 years, likely observing the extension of private properties in their community. A noteworthy 41.8% of household respondents agreed with the statement that in the past 10 years there has been an increase in farming activities in the catchment over the past 10 years, this is expected as farming activities have increased in the UC. The majority of respondents, 53.4% agreed with the statement that in the past 10 years natural land has been cleared and replaced by residential, commercial development, a common characteristic of urban expansion.

From the levels of agreement to the statements above, most of the household respondents are aware of the changes occurring in the catchment (as indicated in table 4.16). Construction activities are common in the peri-urban edge. The household respondents agreed that informal settlements, industrial and construction activities have increased in the catchment over the past 10 years. Although there has not been an increase in the overall size of informal settlements, it is likely that respondents have perceived the increase in density of informal settlement activity as presented in figure 4.5. The increase in industrial activities was positively identified, and although designated areas of construction activity has decreased, the respondents may observe construction activities in their local neighbourhood, such as the extension of households.

Table 4.18: Level of agreement with statements relating to the perceived effects of land use on water quality in the catchment (n=350, in %) (1- Strongly disagree, 2- Disagree, 3- Neutral, 4- Agree, 5- Strongly agree)

Statement	1	2	3	4	5	Mean
All land uses impact the river water quality negatively	8.6	18.3	23.1	29.1	20.9	3
Land use activities closer to the river have an impact on the water quality	6.6	8.6	14.3	48.9	21.7	3
Land use activities further away from the river have a lesser impact on the river water quality	7.7	10.6	21.4	44.9	15.4	3
Agricultural land uses affect river water quality most	12	20.6	34	24	9.4	3
Industrial land uses affect the river water quality most	11.7	11.1	26.5	29.7	20.9	3
Formal residential land uses affect the river water quality most	15.4	21.7	29.4	23.1	10.3	3
Informal residential land uses affect river water quality most	7.4	10.9	24.3	36	21.4	3

Respondents were required to indicate their level of agreement with statements relating to the effects of land use on water quality in the catchment (table 4.18). Half of the respondents agreed with the statement that all land uses impact river water quality negatively. Fewer respondents (26.9%) indicated that they disagreed with the statement and a further 23.1% had a neutral response. The majority of the respondents (70.6%) agreed that land uses that occur closer to the river have a greater impact on the water quality. Just over 60% of respondents agreed that land use activities further away from the river has a lesser effect on river water quality. A further 18.3% disagreed with the statement whilst 21.4% had a neutral response. More respondents (33.4%) agreed that land use practices further away from the river had a lesser impact on water quality. Furthermore, 33.4% disagreed with the statement and 21.4% had a neutral response to the statement.

The majority of respondents (50.6%) agreed that industrial land use affects river water quality the most. A further 22.8% of the respondents indicated that they disagreed with the statement; other respondents (26.5%) indicated that they did not agree nor disagree with the statement. Of the sampled households, 33.4% of respondents agreed with the statement that formal residential land uses impact water quality most, whereas the majority of the respondents (37.1%) disagreed with the statement. Additionally, 29.4% had a neutral response. A noteworthy 57.4% of household respondents agreed that informal residences affect river water quality the most. Of the sampled households, 18.3% of respondents indicated that they disagreed with the statement and 24.3% had a neutral response. From the levels of agreement to the statements in table 4.17, household respondents could not identify downstream, point and non-point effects of pollution on water quality. Neutral responses to the statements indicate that the level of understanding and knowledge of river/catchment health is poor.

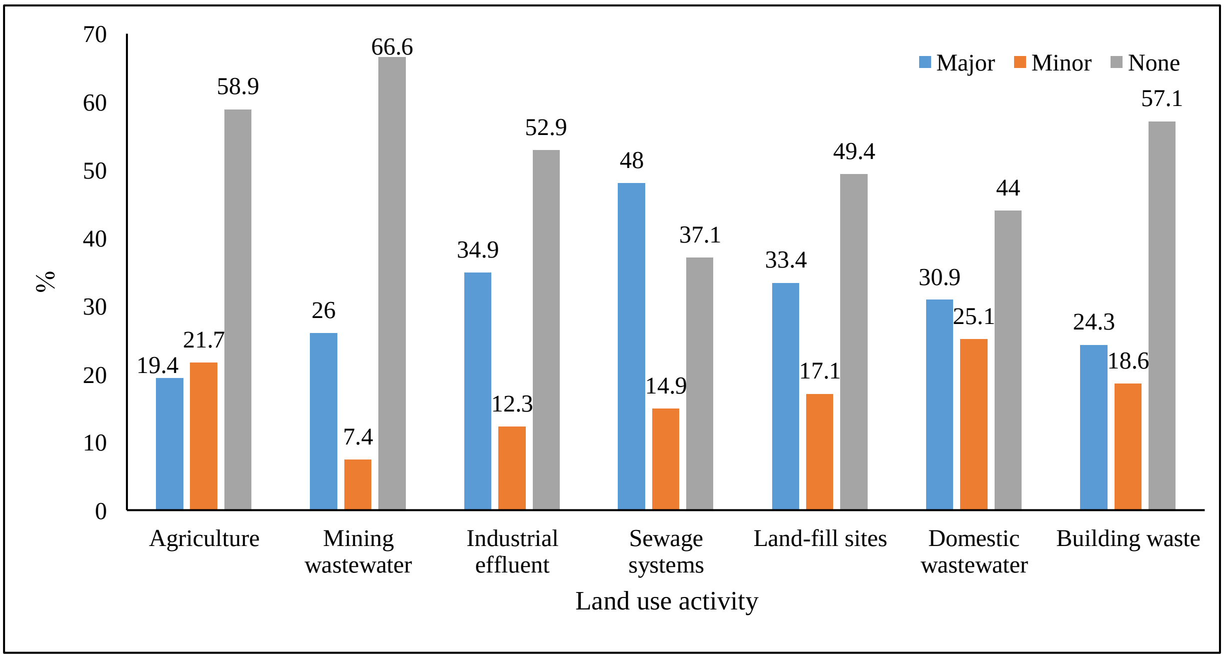


Figure 4.20: Perceived impacts of land use activities on water quality within the Umhlatuzana catchment (n=350, in %)

Respondents were asked to share their perceived impacts and severity of various land use practices on water quality within the catchment. They went on to indicate the nature of the impact. A noteworthy 48% of respondents indicated that sewage systems have a major impact on the water in the Umhlatuzana River. Surprisingly, 37.1% of respondents noted sewage to have no effect on water quality. Aside from personal observations, sewage spills have been reported on numerous occasions in local newspapers, alerting households to the contamination and the risks posed to their health, Despite this, the 37% of respondents are unaware of the of the impact of sewage systems on the river.

Reported sewage WWTW malfunctions and elevated *E. coli* and *T. coli* levels, support this assertion. It is necessary to note that although respondents indicated that formal settlements do not affect river water most, indicating that they do not link sewage systems to formal settlements. Additionally, respondents perceive industries (34.9%) and land-fill sites (33.4%) to have a major impact on water quality in the catchment. Although it was not possible to link land use activities directly with water quality indicators in this study, literature has reported these activities (amongst others) to contribute to the degradation of water systems globally. It is interesting to note that the majority of respondents perceived agriculture (58.9%), industrial effluent (52.9%), building waste (57.1%), and land fill sites (49.4%) to have no impact on water quality. These results indicate that the respondents are not knowledgeable of the factors that affect river water quality.

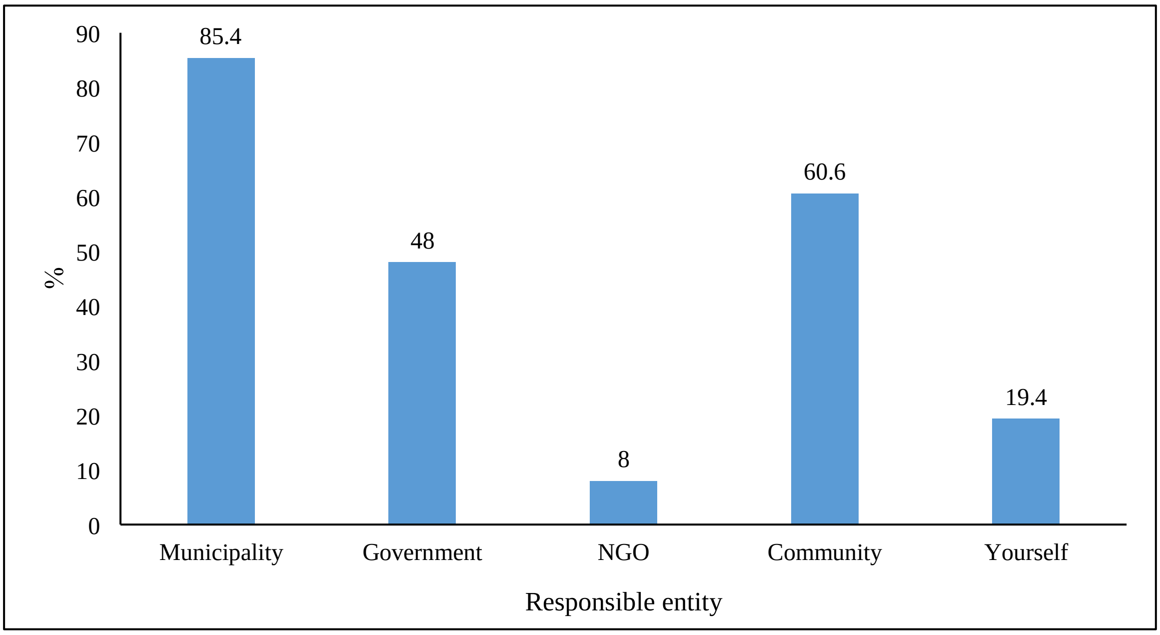


Figure 4.21: Perceptions of who should be responsible for Umhlatuzana river (n=350, in %; Multiple responses permitted)

The household respondents indicated whom they perceived should be responsible for the maintenance and well-being of the river. A majority of respondents (85.4%) indicated that it was the responsibility of the local municipality (eThekwini) to ensure the river is not polluted. Most notably 60.6% of respondents indicate that the community should take responsibility and a further 19.4% indicate that they themselves are responsible for the well-being of the Umhlatuzana River. Additionally, 48% perceived that the national government should be responsible and a minority of respondents (8%) perceived NGOs should be responsible for the river. The response brings to the fore the municipality's role as custodian of the natural environment, likely indicating the respondents' level of trust in the Municipality to safeguard natural resources within their boundaries.

Most notable is the perception that the community should be responsible for the River. This is echoed in the willingness to participate in river related projects/programmes, as 69.7% of respondents indicated that they are willing to participate in water-related projects. Further discussions revealed the reason for wanting to be involved in the maintenance of the river was for a clean river and maintain a healthy environment. Other comments noted that the river is a potential resource that could be used if kept clean, and that the river is part of the community.

The Umhlatuzana catchment has both formal and informal urban settlements, with the latter being concentrated in the MC along with the majority of industrial land uses. The proximity of informal settlements to industrial activity in the catchment is likely due to the legacy of racially based discrimination as well as the availability of marginalised land in proximity to employment opportunities. Although the majority of surveyed households in the catchment indicated that they had physical access to metered water within the dwelling, they identified communal standpipes and the Umhlatuzana River as an additional source for domestic activities. Literature indicates that this is common in South Africa as households may not have the financial ability to make use of indoor metered water, and as such make use of sources due to fear of debt collection and forced droughts from the service provider. This highlights the vulnerability of households to hydrological changes in the catchment.

Use of river water for domestic activities exposes households to the effluent, contaminants in surface runoff and pollutants from agricultural, industrial and construction activities in the catchment. Analysis of selected water quality parameters indicated that water in the Umhlatuzana River has deteriorated as *E. coli* counts and turbidity levels increased and DO decreased. Additionally, qualitative water quality and river health indicators as observed by household respondents also highlight the deterioration of the River water quality over the observed period. Of greatest concern, is although respondents perceived the deterioration of the water quality as well as the health risks associated with utilising water of inferior quality, households continued to use it for domestic activities. This behaviour illustrates that use of the River water is not through preference but is a necessity to satisfy the households' water needs, emphasising the socio-hydrological vulnerabilities of households within the catchment. Additionally, these results illustrate the impact of geography on health and place perspectives.

4.6. Conclusion

Results used in this study were obtained from primary and secondary sources. The water quality data was presented for the Umhlatuzana catchment for an 11-year cycle. Household surveys were administered to 350 households along the catchment. Results show a deterioration of water quality along the catchment and show alarming levels of *E. coli* and *T. coli*. This poor water quality is detrimental to the well-being of riparian organism and overall river health. Furthermore, the poor water quality poses a risk to households and individuals who utilise this source, particularly households within the adjacent informal settlement. Although the demarcated areas for each land uses within the catchment has not changed, the intensity of the activity may have, as exhibited in the increased density in informal settlements. Increases in activities such as industrial and formal settlements highlight the development occurring within the catchment. The pressures land uses exert over surface water is evident within the catchment an effluent spill, which occurred due to leaking WWTW, which is most likely the result of aging infrastructure or growing formal settlement pressures, culminated in the mass death of fish in the Durban Harbour. The following chapter presents the concluding remarks and recommendations.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1. Introduction

This chapter provides a summary of the key findings emanating from this study, recommendations and concluding remarks. The key findings are presented in accordance with the study objectives, research questions and overall aim.

5.2. Summary of key research findings

This study guided by the systems approach argues that society and the natural environment are intricately linked. In this regard, the study sought to examine the links between society, hydrology, and land use typologies. As established by the theoretical frameworks, within the South African context political factors played an equally important role in defining geographic spaces. These events had devastating consequences with lasting legacy impacts that are disproportionally experienced by previously disadvantaged groups. These factors underpin the synopsis of key finds presented below. Below are the discussions that link the key concepts from the conceptual framework that guided the study and themes followed in the data collection instruments. Additionally, these findings are presented in relation to the aim, objectives and research questions that guided the study.

5.2.1. Socio-demographic profile of respondents and households

The Umhlatuzana catchment is inhabited by households with diverse socio-demographic profiles. The levels of household income varied and where characterised by two main groupings: the low-income and upper-income cohorts. It should be noted that within the low-income groups, households showed concerning reliance on state aid as their only source of monthly income. The study revealed the population to be middle-aged. It is concerning to note that many respondents belonged to the economical active cohort yet relied on state grants as their source of monthly income. The levels of education varied. This study shows that most respondent families resided in formal dwelling structures, despite a notable portion of the study population living within with informal settlements.

All households had physical access to electricity and some form of potable water, however, flush sanitation and domestic waste removal services were only available to the middle- and upper-income cohorts. Additionally, some households indicated the use of communal standpipes and the nearby river as a water source and noted sanitation sources to include outside toilets and pit latrines. This is a severe violation of their basic rights and highlights the plight of poor across the country. These trends of disproportionate access to basic services are unsurprising and are among the many legacies of the country's political history. The levels of *E. coli* and other pollutants suggest that those households in contact with the water face severe health risks. The dependence on state grants by the majority of households and the average household income presented in this study, indicate that the households within the catchment have a lower level of economic power and could experience difficulties in accessing appropriate and sufficient medical assistance. Moreover, the majority of households resided in the community for more than 10 years suggesting long-term exposure and persistent health risk. The residency within the area can also be seen as an opportunity since respondents possessed long-term understandings of changes to the physical and social environments.

As discussed in chapter 4, household and respondent socio-demographic profiles are pertinent when examining the vulnerability of the catchment community. This is of particular importance in a developing country setting such as South Africa, where the political historical impacts access to basic services and exposure to environmental degradation as discussed in the Geography of health conceptual framework in chapter 2. This study found that the community in the Umhlatuzana catchment may be considered vulnerable, due to various factors such as income source and average, number of dependants and the nature of interactions with the Umhlatuzana River.

5.2.2. Umhlatuzana water quality

In assessing how the water quality has changed in a period of 11-years, key water parameters were selected. The timeframe used in this study was systemically chosen based on completeness of water quality data from the local municipality. Even though continuous water quality assessments are recommended by the WHO and DEA, some variables had no data for periods of more than 6 months in the year, in some instances. The disrupted collection of data and the limited comparability in available data is a serious challenge when addressing water quality.

This study observed that pH levels remained within acceptable national and international guideline limits throughout the catchment for the observed period. Within these levels, there are no risks to health or the environment as pH levels if alkaline alter the toxicity of pollutants found in the river and when acidic increases the solubility of other elements such as copper and iron. Additionally, TDS results remained within the acceptable range where there is likely to be no impact on human health such as an imbalance of salt in the body, which is likely to cause hypertension, kidney failure and stone deposits. Overall, TDS levels decreased significantly in the UC over the years.

Turbidity in the Umhlatuzana River consistently exceeded acceptable range and poses a risk to ecological function and riparian fauna and flora within the catchment. More importantly, this study established turbidity levels increased significantly from 2004 to 2014 within the catchment. Although not a direct human health threat, turbid waters contain high levels of particulate matter (which serve as substrate for the growth of pathogenic organisms) that contribute to increased microbial and parasitic contamination. In particular, the MC regions showed highest recorded values and could be explained by the presence of the many wastewater treatment sites. Similar trends were noted in turbidity levels along the UC, however, in this instance, the intense agricultural activities and vacant land portions may have been the main contributing factors. Based on these results the water from the river is not suitable for recreational, consumption or domestic use.

This study found that *E. coli* levels in the UC and MC increased significantly from 2004 to 2014, with the MC showing some of the highest recorded values. More concerning is that informal settlements dominated land use in the MC region. These findings suggest that whilst the wastewater treatment works may have contributed to the *E. coli* levels, it is also evident that the river was being used to dispose untreated household sewage. In addition, results show that a small portion of the sampled households consumed river water and did so daily. The multiple sources of *E. coli* into to the river could explain the alarming levels. Water that has been contaminated by *E. coli* increases the risks of microbial infections, and is linked to diseases such as gastroenteritis, cholera, and typhoid fever. The *E. coli* contributes to the poor quality of the Umhlatuzana river water as it exceeds national and international levels exponentially and is thus not suitable for domestic use. In this case, poses a serious threat to the health of surrounding communities.

T. coli in water indicates the presence of microbial growth in the distribution system, which includes bacteria of faecal origin such as, *Escherichia*, *Serratia*, *Klebsiella* and *Enterobacter*, that are associated with diseases such as cholera, typhoid fever, gastroenteritis and salmonellosis. Similar to the outcomes of *E. coli*, this study found that *T. coli* exceeded national and international guideline limits. Furthermore, *T. coli* levels were highest in the MC and lowest in the UC. The high levels of *T. coli* increase the possibility of river water users contracting water related diseases, contributing to increased vulnerability to health risks.

In relation to DO, data could only be analysed for a period of 6 years since the municipality stopped data collection for this variable in 2009. Although human health is not impacted directly by DO, it is required for the survival of aerobic organisms in the water. Any depletion of oxygen may alter the ecology of the river. In this study, DO levels in the UC correlated with those in the MC, additionally, DO levels were lowest in the LC making it incapable of supporting riparian and aquatic fauna and flora.

The Municipality implemented the RWQI in 2006 as a scale to rank the state of water quality in rivers in eThekwini. The Umhlatuzana River was characterised as poor for most of the months in the years between 2006 and 2014. However, since the municipality only prioritises rivers that are classified as being critical, it is unlikely that any ecological remediation plan will be implemented for the Umhlatuzana River. More concerning is that the RWQI categories do not necessarily include impact on human health. This system can be seen as reactive and ineffective under the current circumstances. For example, South Africa is currently facing one of the worst droughts in history and monitoring systems need to serve as early warning systems that are proactive in maintaining ecological function and water quality within all rivers.

The results of the observed parameters indicated an overall decline in the already poor water quality of the Umhlatuzana River. Parameters such as *E. coli*, turbidity and *T. coli* indicate that the water is not suitable for use and is likely to cause illness or adverse health effects, if not treated. Additionally, declining levels of DO and increased levels of turbidity would alter the ecology of the river. The declining trend of water quality indicates poor ecosystem health and concern for public health and safety.

Seasonal and flow differences do not account for the exponential oscillations observed in many of the water quality parameters, as such, the influence of land use activities in the catchment are considered an important when examining the decline of water quality in the Umhlatuzana River. The observed influences are supported by the human-water dynamics of the socio-hydrology conceptual framework, incorporating both social and political factors which impact the socio-hydrology in a South African catchment.

5.2.3. Land use changes within the Umhlatuzana catchment

This study examined the land use activities and changes in the catchment to provide insight into the influence of land use on water quality and therefore socio-hydrological vulnerability in the catchment. High-resolution SPOT imagery, geo-referenced orthophotos and municipal spatial data was used to examine land use change within the catchment from 2003 to 2014. Results show a variety of land use typologies within the Umhlatuzana catchment from 2003 to 2014, however, no significant differences were noted in intensity and typology across the years. Nonetheless, water quality results and land use typology yield some associations. For example, the upper catchment was dominated by farming activities and formal settlements contributing to increased surface run-off and therefore higher levels of turbidity. Similar trends were noted in the mid and lower catchments, which were dominated by informal and industrial activities, respectively. Similarly, the lower and mid catchments housed a number of wastewater treatment works, septic tanks, and informal residence. The *E. coli* and *T. coli* levels within these zones were significantly higher level than the rest of the catchment.

The land use over the MC is dominated by formal and informal settlements that are often linked to increased turbidity and bacterium in water, respectively. The impervious surfaces of formal settlements and the trade effluent points may be associated with the high turbidity levels. In the LC, numerous industrial areas and trade effluent points are located along the main river. The presence of industrial outlets may account for the consistently low DO levels seen in the lower catchment, remaining below the minimum requirement for the majority of the observed period. The presence of industrial activities increases the likelihood of pollution from industrial wastewaters increasing turbidity. Spatial data revealed that construction activities decreased, while industrial land use and formal settlements increased. It is important to note that there was also a decline in informal settlement as it was replaced by formal settlements, due to new construction or rezoning. The study found that water quality was poorest in the MC, with this area of the catchment having extensive informal and formal settlements around the river. Settlements are often identified in literature as the cause of increased *E. coli* and *T. coli* levels. Additionally, trade effluent pipes in the catchment are located in the MC and LC, which may explain the high turbidity levels presented in the water quality results.

This study showed that alignment of water quality records with specific land use types. This can be seen as validation for the chosen methodological approach where oscillations in water quality are examined in relation to the entire catchment and the associated land use practices. The argument underscored by the multiple conceptual frameworks guiding this study further evidences the need to adopt a systems approach to environmental monitoring, especially in rapidly developing cities such as eThekwini. Additionally, given the legacy impacts of apartheid, examining public health and water quality through multiple lenses may yield understandings that are more robust. This study demonstrates that the examination of socio-hydrological cycles and land use change in water quality studies provided enhanced environmental knowledge and monitoring.

5.2.4. Household utilisation of water within the Umhlatuzana catchment

To understand household vulnerability more comprehensively, it is vital to gain insight to the level of exposure the community has to the river water. This exposure may be determined by examining the community's interaction with the river water, by identifying the type of contact, duration and frequency of interaction. Based on the results obtained from this study, a small proportion of households in the catchment make use of the river water for domestic purposes. Additionally, the majority of these households indicated that they do not treat the water before it is used as they do not think it is necessary. Households used the river water for the watering of edible plants, drinking, food preparation, personal hygiene, sanitation, and domestic activities such as washing crockery and cutlery. These activities present a higher risk to users as it may contaminate foods resulting in gastrointestinal illnesses or diseases, particularly as majority of these households do not treat the water before use. Activities that resulted in skin contact with the water were washing of clothes, use of water for religious and cultural practices, and other activities such as washing cars, producing cement blocks, and swimming. The health concerns as a result of engaging in such activities is that skin contact with the water increases the risks of contracting water-related infections such as bilharzia. The frequency and duration of contact with the river indicates that the River is used to perform essential household activities and is used to satisfy the households' basic needs. Female household members are particularly vulnerable as they are primarily responsible for the completing the household activities using river water.

5.2.5. Perceptions of water quality and land use in the Umhlatuzana catchment

The respondents indicated that the river water has deteriorated, echoing the findings of the water quality analysis. The alignment between perceptions and the results of the water quality analysis indicates that the community is aware of the changes in their surrounding environment, even though they did not deem it harmful. Respondents also identified several water related illnesses and diseases, particularly symptoms of gastroenteritis distress. This indicates that the respondents are aware of the possible health outcomes of ingesting contaminated water. Although aware of the risks to health, most respondents were not aware of the factors that affect river water since the majority indicated industrial effluent, mining wastewater and agriculture to have no impact on river water. Interestingly, despite the perceptions held by most respondents, some households still used the river for domestic purposes, including consumption. This is extremely worrying given the persistent level of *E. coli* and *T. coli*.

Although the majority of respondents indicated that the river has an impact on their well-being and the well-being of their community, a minority of respondents agreed with the statement that water quality is an important issue to be addressed in the community. Although water quality was identified as a problem in the community, it is not considered a priority. This could be attributed to other challenges such as lack of water and sanitation infrastructure may be regarded as a more urgent need in the community.

The majority of respondents indicated that the eThekwini municipality should be responsible for maintaining the river. Respondents view the local municipality as the authority of public spaces and resources, and as such are seen as suitable custodians for the well-being of the river and by extension the community. Moreover, respondents indicated that the community should also be responsible for the well-being of the river, with the majority of respondents noting that they would be willing to participate in projects/programmes centred on the river. This willingness to participate in such programmes can be seen as an opportunity for future community-based initiatives.

Moreover, land use perceptions provided insight into the community's level of awareness of their surroundings, as well as their understanding of the linkages between water and land use. A lack of awareness of these dynamics and changes in the landscape is likely to increase the community's vulnerability to unanticipated changes. From the levels of agreement to statements pertaining to land use in the catchment, it is evident that the community is not fully aware of the links between land use and water quality, land use changes in the catchment. The majority of the community perceived informal and construction activities in the catchment to be increasing, which does not concur with the finding that these land use activities have decreased from 2003 to 2014.

Although respondents indicated that the overall quality of the river has declined, this did not deter households from using it for domestic activities. As discussed in chapter 4, although aware of the health risks related to using water of poor quality, these risks may be considered acceptable as use of the River water is due to necessity and not preference. The multiple conceptual frameworks used in this study indicate that the qualitative nature of such decision making needs to be investigated and incorporated into environmental monitoring approaches.

South Africa can be constituted as a unique example as household location and exposure to risk is influenced by the discriminatory political history of Apartheid, as underpinned by place perspectives. Additionally, through racially based laws and policies, the location of communities was purposive, forcing them into unsuitable areas. Moreover, obstacles such as corruption in awarding service provision tenders, further impoverish communities as it is increasingly difficult to access basic services such as water and sanitation. As a result, it is the poorest vulnerable households who are located in dismal environmental conditions and exposed to health risks.

5.3. Recommendations

5.3.1. Pro-active response from local government

As a government authority, eThekwini Municipality is the entity responsible for the safeguarding of public spaces and environments. To this end, the Municipality collects data on water quality for all rivers within its boundaries, primarily for observation purposes, which assists in identification and prioritisation of critical rivers. The results in this study indicate that action must be taken in order to avoid the further deterioration of the river. This is of particular importance due to the community's use of the river as evidenced in this study. Of concern are the *E. coli* and *T. coli* levels, which pose significant risks to the health of all households that use the river. Moreover, evidence of failed and insufficient infrastructure has contributed to the deterioration of the water quality exhibited in this study. A key recommendation emanating from this study is that eThekwini Municipality needs to assume a more proactive role in the management of river systems and catchments. Although samples are collected and tested, there is limited evidence that demonstrates immediate action to identify pollution sources and address impacts. Investigations into spikes and increases in parameters such as *E. coli* should be mandatory due to its impact on health. Continuous and consistent monitoring and reporting is crucial.

In addition to this, the municipality must increase its efforts to inform communities of the status of their local rivers and any possible risks it could pose to their health. The Municipality presents maps of historical and current water quality in local rivers on their website; colour coded according to the RWQI categories, on a monthly basis. However, local communities without internet access are not able to access these reports. A concerted effort needs to be adopted to disseminate findings on river water quality as results of this study indicate that local rivers support daily water needs in communities. In this regard, community-meetings and awareness campaigns could be a viable option to disseminate information and build awareness across several socio-economic groups. Moreover, the municipal website is hosted in English, thus, the content could be inaccessible to many. In an attempt, to include a greater proportion of households that may be a risk due to deteriorating water quality, there needs to multi-lingual initiates across many media platforms.

5.3.2. Maintenance of infrastructure

Elevated levels of *E. coli* and *T. coli* as well as reports of failed WWTW and burst sewage pipes indicates that the pollution of the river is due to poor maintenance of infrastructure. As a response, the Municipality needs to improve maintenance plans, such as shutting valves and redirecting sewage to repair and replace parts before failure. Additionally, closer monitoring of infrastructure and reporting of malfunctioning WWTW and burst sewage pipes must be prioritised and monitored more closely and requires immediate reaction from the Municipality. These could include punitive measures for environmental degradation and violation of environmental legislature. In this regard, the establishment of early warning systems could greatly reduce risk and deterioration. As mentioned, earlier the efforts to include community members by encouraging the reporting of burst pipes and responding to logged calls is an effective action that may be taken to avoid pollution of catchments. Furthermore, taking preventative steps to avoid the deterioration of rivers may influence communities' perception on the importance of rivers.

5.3.3. Community participation

Results in this study indicate that the community requires awareness campaigns on water quality, rivers and its' associated impacts. The community exhibited a basic understanding of the impacts of water quality on health and the vulnerability of household members to these impacts. The educational material should emphasise the importance of treating water before use and the consequences of contact with polluted water. Treatment methods and background details of why it is necessary to treat water before use will empower the community to take action in protecting their health, and provide them with the knowledge that water quality does not only impact those who drink untreated water. Moreover, the inherent importance of river systems is vital to provide the community with greater insight and knowledge of the relationship between all activities in a catchment and water quality. Materials used during campaigns should be appropriate for the community setting and should be easy for all education levels to understand. Additionally, the catchment community indicated a willingness to participate in programmes centred on the Umhlatuzana River. Including households in the monitoring of the river will not only increase the monitoring of the river but also allow households to relate to their surrounding environment, thereby improving the reception of educational messages (such as those regarding pollution).

5.4. Concluding remarks

The examination of water quality parameters cannot be isolated from surrounding land use activities in the catchment, due to the interconnected nature of land use activities and water quality. This study adopted a mixed methodological approach to gage historic changes in water quality and land use change. Another important dimension in this nexus is the influence of social systems. This study was conceptualised to highlight these inter-relations in a hope to provide more nuanced information on socio-environ-hydrological systems. More importantly, this multi-conceptual approach yielded further sight on risks to community health and vulnerability.

The water quality of the Umhlatuzana River was observed for a period of 11 years, with findings indicating that the quality of water in the catchment has declined. Land use practices and changes in the catchment during this time are likely to have affected the water quality, particularly instances of sewage pollution reported in media, which correlate with results obtained in this study. It is however, not possible to infer causation or definitively identify the source of pollution in the catchment given the diverse activities that characterise the catchment area. There was an overall decline in the quality of water in the Umhlatuzana River. The levels so of *E. coli* and *T. coli* are alarming and exceed local and international water quality standards for recreational and domestic use. This study shows that the current environmental conditions, specifically, water quality can be deemed a serious threat to human health since a number of households used untreated river water for domestic activities, including consumption. More concerning is that these households did not perceive the water to be harmful to them. Even though the more frequent activities can be described as low risk, for example washing of clothes and cutlery, the risk is contamination is very high.

In terms of the parameters used to assess water quality, the increased levels of *T. coli, E. coli,* turbidity and decline in DO levels indicates that the river water poses a risk to the well-being of the environment. At the observed levels, the river's capacity to sustain life is limited. Land use activities such as the clearing of natural landscapes and increase in impervious surfaces associated with formal settlements effects the quality of the water. These changes in the river pose health risks to the community who makes use of the river for domestic, cultural and agricultural activities. Without treating the water before use, households are highly vulnerable and susceptible to water-related illnesses and diseases.

Situating health in the context of space and place allowed for the dynamics and interaction between communities and their surrounding environment to be investigated in greater depth, situating place as an important aspect of health. Moreover, the geographies of health allowed for the investigation of how households conceptualise and perceive their surroundings. Additionally, adopting a socio-hydrology perspective, as done in this study, is imperative for unpacking household interactions with water. This framework provided understanding of importance of the river in the different facets of its users, as evidenced in the myriad uses of the Umhlatuzana River. Such insight is of relevance to authorities who are entrusted as custodians of rivers, as this assists in developing management approach that are cognisant of the health risks associated with different pathways of exposure.

Future research on land use practices and socio-hydrology needs to explore the identification of point and non-point source pollution, as this will aid in developing more robust monitoring and responsive catchment management plans, resulting in more proactive approaches by those entrusted to manage rivers. With regards to the community, it is necessary to increase attention on vulnerable groups within the catchment, particularly among low-income households and informal settlements since these households interact with the river directly and utilise it for basic needs. Risk assessments should be conducted more frequently since these can be important in identifying the health risks these communities face in fulfilling their water needs. Additionally, the health of community members must be investigated and monitored to establish the extent to which their health is affected due to their reliance on the river. Furthermore, collaborations between the local Municipality, community groups and local clinics would improve the sharing of data and identify as well as address the needs of the community. These projects would not only improve management of the catchment but also address the health of vulnerable communities.

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Sampling site number:	Date:
Questionnaire no:	
Name of fieldworker:	
Distance from river:	

APPENDIX 1: Household Survey

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

UMHLATUZANA COMMUNITY PERCEPTION AND WATER UTILISATION QUESTIONNAIRE.

Good day my name is … and I am undertaking a survey of public perceptions in your community on behalf of a student, Miss Candice Webster for her MSc degree at the University of KwaZulu-Natal. May I ask you a few questions regarding water quality? Your answers will be treated confidentially and anonymously. If at any time during the interview you feel you do not wish to continue, please feel free to do so. Thank you for agreeing to be interviewed.

SECTION A: SOCIO-DEMOGRAPHIC PROFILE OF RESPONDENTS

A1. What is your age (in years)? ______________________

A2. What is your sex? (Note, don't ask)

1. M	2. F

A3. What is your employment status?

1. Employed	2. Unemployed	3. Self-employed	4. Retired	5. Medically bordered	6. Student	7. Other (specify)

A4. What is your highest level of formal education attained?

1. No formal education	2. Partial primary	3. Primary completed	4. Partial secondary- Grade 10	5. Secondary completed	6.Certificate/diploma
7. Undergraduate degree	8. Postgraduate degree	9. Adult Based Education (ABED)	10.Other (specify)		

A5. What is your monthly income (in Rands)?

0. None	1. <1500	2. 1500-3000	3. 3000-5000	4. 4500-6000	5. 6000-7500	6. 7500-9000	7. 9000-10500	8. >10500	9. Other (specify)

SECTION B: HOUSEHOLD PROFILE

B1. How many members in your household?

1. Male		2. Female	

B2. What are the ages of the members of your household?

1. 0 - 4	2. 5 - 9	3. 10- 14	4. 15- 19	5. 20 - 24	6. 25- 29	7. 30-34	8. 35- 39	9. 40-44	10. 45-49	11. 50-54	12.55-59	13. 60-64	14. 65+

B3.Can you specify the level of education of the members of the household?

1. No formal education	2. Partial primary	3. Primary	4. Partial secondary	5. Secondary	6. Certificate/diploma	7. Undergraduate degree	8. Postgraduate degree	9. Adult based education (ABED)

B4. Please specify the sources of monthly household income (in Rands).

Sources	Amount in Rands
1. Formal employment	
2. Small business/ informal trading	
3. Sale of agricultural produce	
4. Remittances	
5. Old age pension	
6. Child grant	
7. Disability grant	
8. Other (specify)	
TOTAL	

B5. How long have you lived in this area?

1. Less than a year	2. 1-3 years	3. 4-6 years	4. 6-8 years	5. 8-10 years	6. More than 10 years

B6. What type of dwelling do you currently live in?

1.Formal brick	2.Traditional	3.Informal	4.Other (specify)

B7.1. What are your main sources of energy for heating?

1. Electricity	2. Gas	3. Fuelwood	4. Charcoal	5. Paraffin	6. Other (specify)

B7.2.What are your main sources of energy for cooking?

1. Electricity	2. Gas	3. Fuelwood	4. Charcoal	5. Paraffin	6. Other (specify)

B7.3.What are your main sources of energy for lighting?

1. Electricity	2. Gas	3. Fuelwood	4. Charcoal	5. Paraffin	6. Other (specify)

B8. What type of sanitation do you have access to? (Multiple responses permitted)

1. Flush toilet inside dwelling	2.Flush toilet outside dwelling, but within plot	3. Pit latrine	4.Ventilated improved pit latrine (VIP)	5. Bush/veld	6. Urine diversion toilet (UDT)
7. Bucket system	8.Nearby river/water body	9. Communal pit latrine	10. Communal VIP	11. Portable chemical toilet	12. Other (specify)

B9. Do you have access to potable water?

1. Yes	2. No

B9.1. If yes, please specify the type.

Sources	Distance
0. Metered water within dwelling	
1. Outside tap on plot	
2. Communal stand pipe	
3. Communal tank	
4. Tanker truck	
5. Borehole	
6. Umhlatuzana river	
7. Harvested water (Jojo tank)	
8. Other (specify)	

CODES

Distance
1. 0 - 50 m
2. 50 - 100m
3. 100 - 500m
4. 500m - 1km
5. 1 - 3km
6. More than 3km

B10. What activities take place on the property currently? (Multiple responses permitted)

0.None	1.Crafting	2. Business/Spaza shop	3.Traditional medicine	4.Crop production	6.Livestock rearing	7. Other (specify)

SECTION C: PERCEPTIONS AND USES OF LAND AND THE UMHLATUZANA RIVER

C1. Do you use water from the Umhlatuzana River?

1. Yes	2. No

C1.1. If yes, do you treat the river water in any way before it is used?

1. Yes	2. No

C1.1.1 If yes, what methods do you use? (Multiple responses permitted)

1.Bleach	2.Boil	3.Water filter	4.Strain with cloth	5. Chlorine	6.Other (specify)

C1.1.2. Can you specify how the water is used by the members of the household?

	a) Frequency	b) Who	c) Detergent used	d) Duration
1. Preparation of food				
2. Washing of clothes				
3. Washing of dishes and utensils				
4. Watering of edible plants				
5. Personal hygiene				
6. Drinking				
7. Religious/cultural				

Frequency
0. Never
1. Daily
2. Weekly
3. Monthly

Household member
0. Everybody
1. Children (0-16 years)
2. Adults (16-64)
3. Females only
4. Males only
5. Adults 65+

Detergent/product
0. None
1. Washing powder
2. Soap bars (e.g. Lux, sunlight)
3. Liquid detergent (e.g. sunlight)
4. Bleach (e.g. Jik)
5. Other (specify)

Duration
1. 0-10 mins
2. 10-20 mins
3. 20-30 mins
4. 30-60 mins
5. 1-2 hours
6. More than 2 hours

C1.2. If no, why not? (Multiple responses permitted)

1. Lack finances to do so	2. Don't have the equipment needed	3. Too time consuming	4. Don't think it's necessary	5. I don't know how	6. DescOther (specify)

C1.3. If you drink the water how has the taste changed?

0. No change	1. Metallic	2. Soapy	3. General bad taste	4. Chemical taste

C2. If you use the river for the washing of clothes, where do you dispose of the remaining water?

1. Dispose in toilet facility	2. Onto ground near home	3. Onto ground away from home	4. Into nearby river	5. Into sewer

C3. If you use the river for the washing of dishes, where do you dispose of the remaining water?

1. Dispose into toilet facility	2. Onto ground near home	3. Onto ground away from home	4. Into nearby river	5. Into sewer

C4. Do you fish in the Umhlatuzana river?

		Frequency		
Purpose	**Y/N**	**Daily**	**Weekly**	**Monthly**
1. Commercial				
2. Subsistence				

C5. Have you noticed any changes in the quality of the river water in the past 10 years?

1. Yes	2. No

C5.1. If yes, please indicate what you have observed regarding the change in quality of the river water.

0. None	1. Remained the same	2. Deteriorated	3. Improved

C6. In the past year, how would you describe the general colour of the river water?

0. Clear (no colour)	1. Brownish	2. Greenish	3. Blue	4. Grey

C7. In the past year, how would you describe the general taste of the river water?

0. Tasteless	1. Metallic/bitter	2. Chlorine	3. Earthy/musty	4. Soapy

C8. In the past year, how would you describe the general odour of the river water?

0. None	1. Sewage	2. Chemical	3. Marshy	4. Soapy

C9.Have you seen the following being disposed into the river? If yes, how often?

Items	1. Yes/ 2. No	3.Frequency
1. Plastics		
2. Tins/metals		
3. Domestic waste (garbage)		
4. Organic waste (crops and gardens)		
5. Waste water		
6. Human waste (adult and children)		
7. Building waste		
8. Paints/ solvents/ oils/ home chemicals		

Frequency
1. Daily
2. Weekly
3. Monthly

C10. Does your opinion of the water's quality affect the way you utilise it? Please elaborate.

1. Yes	
2. No	

C11. Do you think poor water quality has a negative impact on the health of yourself and other members of the household?

1. Yes	2. No

C11.1 If yes, do you think poor water quality could have the following health impacts? (Multiple responses permitted)

1. Weight loss	2. Skin irritation	3. Headache	4. Nausea/vomiting	5. Fatigue	6. Stomach ache	7. Diarrhoea	8. Other (specify)

C12. Would you utilise the river for the following purposes if quality/access improved?

	Improved quality (1. Yes/2. No)	Improved access (1. Yes/2. No)
1. Preparation of food		
2. Domestic chores		
3. Subsistence agricultural activities		
4. Commercial agricultural activities		
5. Personal hygiene		
6. Drinking		
7. Other (specify)		

C13. Which household members do you think are most at risk of contracting illnesses from the use of river water? (Choose 1 only)

	Reason
0. None	
1. All	
2. Children (0-16)	
3. Females	
4. Males	
5. Elderly (65 +)	

Reason
1. Collects the water
2. Uses the water to perform chores
3. Plays in the water
4. More susceptible to illness
5. Other (specify)

C14. Please rate your level of agreement with the following statements with regards to water quality (0= don’t know, 1= strongly disagree, 2= disagree, 3= neutral, 4= agree, 5= strongly agree)

	0	1	2	3	4	5
1. The water quality of the river has a direct impact on my well-being.						
2. The water quality of the river has an impact on the well-being of my community						
3. The water quality of the river is only important to the people who drink from it.						
4. Water quality of a river only matters if people are getting sick.						
5. Water quality is an important issue to be addressed in the community.						
6. Children in the community must be taught the importance of a clean river.						
7. The community is well informed/understands the water quality in the Umhlatuzana River.						

C15. Please rate your level of agreement with the following statements with regards to land use (0= don’t know, 1= strongly disagree, 2= disagree, 3= neutral, 4= agree, 5= strongly agree)

	0	1	2	3	4	5
1. In the past 10 years there has been an increase in informal dwellings						
2. In the past 10 years there has been an increase in industrial activities in the catchment						
3. In the past 10 years there has been an increase in construction activities						
4. In the past 10 years there has been an decrease in farming activities						
5. In the past 10 years natural land has been cleared and replaced by residential, industrial and commercial development						

C16. Please rate your level of agreement regarding the effects of land use on water quality. (0= don’t know, 1= strongly disagree, 2= disagree, 3= neutral, 4= agree, 5= strongly agree)

	0	1	2	3	4	5
1. All land uses impact the river water quality negatively.						
2. Land use activities close to the river have an impact on the water quality.						
3. Land use activities further away from the river have a lesserer impact on river water quality.						
4. Agricultural land uses affect river water quality most.						
5. Industrial land uses affect river water quality most.						
6. Formal residential land uses affect river water quality most.						
7. Informal residential land uses affect river water quality most.						

C17. Do you think the following activities influences the water quality in the Umhlatuzana River.

Contributors	1. Yes/2. No	1. Major contributor	2. Minor contributor
1. Agricultural activities			
2. Wastewater from mining			
3. Wastewater from manufacturing plants			
4. Sewage systems			
5. Land-fill sites			
6. Urban/domestic wastewater			
7. Building waste			
8. Other (specify)			

C18. Who do you think is currently responsible for ensuring the water is of acceptable quality?

1. Municipality	2. Government	3. Non-governmental organisation (NGO)	4. Nobody	5. Other (specify)

C18.1. Are you satisfied with their efforts? Why?

1. Yes	
2. No	

C19. Who do you think should be responsible in ensuring that water is of an acceptable quality? (Multiple responses permitted)

1. Myself	2. Community	3. Non- governmental organisation (NGO)
4. Municipality	5. Government	6. Other (specify)

C20. Are you aware of any community participation/educational programmes centred on water conservation/ protection?

1. Yes, name of the programme	
2. No	

C20.1. Do you participate in any of these programmes? Why?

1. Yes	
2. No	

C20.2. Would you be willing to participate in any community projects centred on the Umhlatuzana River?

1. Yes, why?	
2. No, why?	

C21. What do you think can be done to improve the water quality of the Umhlatuzana River?

Thank you for your time, have a good day.

APPENDIX 2: Observational Checklist

Site number:___________ Location:__________________________ Date:_________________ Time: _________ Weather conditions:____________________________

GPS coordinates: ____

1. Surrounding land use type(s) (within 50 m of the river)

1. Formal residential	2. Informal residential	3. Agricultural	4. Industrial	5. Open space	6. Other (specify)

2. Describe vegetation type(s) (within 0-10 m of the river; multiple selections permitted)

1. Natural	2. Agricultural	3. Combination of natural and agricultural	4. Presence of aquatic plants	5. Little to no vegetation in area of interest	6. Other (specify)

3. Number of people in contact with the water body for duration of observation period

1. 0	2. 1 to 5	3. 6 to 10	4. 11-15	5. More than 16 (specify)

4. Description of users (multiple selections permitted)

1. Males		1.Children		2.Adults		3.Aged (>65yrs)		2.Females		1.Children		2.Adults		3.Aged (>65yrs)	

5. Activities occurring in or in close vicinity to river (within 0-10 m of the river; multiple selections permitted)

0. None	1. Washing	2. Bathing	3. Water collection	4. Swimming	5. Fishing	6. Religious practices
7. Disposal of faecal matter	8. Pit latrines or UD toilets	9. Industrial effluent	10. Domestic effluent	11. Agricultural effluent	
12. Sand mining	13. Dumping of domestic waste	14. Dumping of other waste material (specify)	15. Planting	16. Grazing	17. Other (specify)

6. Colour

0. Clear	1. Blue	2. Green	3. Brown	4. Reddish	5. Cloudy/ Murky	6. Other (specify)

7. Turbidity

1. Very low	2. Low	3. Medium	4. High	5. Very high

8. Evidence of pollution

0. None	1. Plastics	2. Metals/tins	3. Papers	4. Sewage	5. Kitchen waste
6. Organic material	7. Foam	8. Oil	9. Other (specify)		

9. Odour

0. None	1. Damp/musty	2. Detergent	3. Chemical	4. Human excreta	5. Chlorine	6. Fishy	7. Other (specify)

Comments:

____