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YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
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RADIONUCLIDE AND HEAVY METAL CONTAMINATION OF DRINKING WATER SOURCES IN THE WONDERFONTEINSPRUIT CATCHMENT, SOUTH AFRICA

BY

TAFADZWA MARARA (22082905)

MSc ENVIRONMENTAL SCIENCE

GEOGRAPHY AND ENVIRONMENTAL SCIENCE

FACULTY OF AGRICULTURE, SCIENCE AND TECHNOLOGY

SUPERVISORS : DR. L.G PALAMULENI

: PROF. E.E. EBENSO

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DECLARATION

I, TAFADZWA MARARA (student number: 22082905), hereby declare that this research is my original work. Unless specifically stated, all the references listed have been consulted. The work of this dissertation is a record that has been done by me and has not been previously accepted for any higher degree or professional qualification at any other educational institution.

Signed......T Marara...

MISS TAFADZWA MARARA

Date ......28 - 03 - 2013......

This dissertation has been submitted with my approval as a university supervisor and would certify that the requirements for the applicable Masters of Environmental Science degree rules and regulations have been fulfilled.

Signed...

Dr .L.G. PALAMULENI

Date..................28 - 03 - 2013........................

Signed...

PROF E. EBENSO

Date...

ABSTRACT

The Wonderfonteinspruit (WFS) catchment is home to thousands of people, amongst them a significant number of informal settlement inhabitants, which largely rely on the Wonderfonteinspruit for domestic consumption on a daily basis or during water scarce periods. This research was aimed at: establishing the water sources and uses, the water quality and consequently the health risks arising from consumption of the water. Another aim was to investigate the challenges associated with accessing potable drinking water, and the effectiveness of the implementation of the water institution in South Africa with special reference to this catchment. Using questionnaires administered to communities, mines and the municipalities, data was gathered on the drinking water sources, from which water samples were collected and analyzed for heavy metals (As, Cd, Pb, Zn, Cd) and radionuclides (U isotopes) using inductively coupled plasma mass spectrometry (ICPMS) in the dry and wet seasons. In addition, the radiological absorbed dose and risk quotients for the various contaminants were computed using the contaminant concentrations. Research in the area has shown that there are radionuclides and heavy metals trapped in sediments of the Wonderfonteinspruit River. The findings revealed that there is significant usage of river water from the WFS for domestic consumption, either as an alternative or a main water source especially in the informal settlements. The quality of water from this river is not in compliance with the SANS 241 and WHO 2011 drinking water standards for As and U , thus statistically significant associations were observed between the concentrations of these contaminants in water and the occurrence of skin lesions and kidney inflammation respectively. As such, informal settlements of Carletonville, Bekkersdal and Khutsong are at potential risk of serious health problems as a result of their usage of the WFS for domestic consumption. A review of contemporary literature and government publications revealed that the poor implementation of the water institution could be attributed to non-collaboration between the various stakeholders. This study developed useful indices which can be used to measure community perception and a model for integrated waste and water resources management. Findings from this study are thus pertinent as they provide a baseline from which further epidemiological studies can be undertaken. Furthermore, these findings also have serious policy implications and could then be used in advancing water resources management in South Africa.

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All the above mentioned people I believe were sent to me by The Almighty and I thank Him, for taking me from strength to strength, for protection and guidance, for overcoming all the obstacles. Thank you Lord!

DEDICATION

To my mother, Felistas Evelyn Marara.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

AMD-Acid Mine Drainage

BPGs-Best Practice Guidelines

BURP-Bekkersdal Urban Renewal Programme

CMAs-Catchment Management Agencies

DNA-Deoxyribonucleic acid

DWAF-Department of Water Affairs and Forestry

EIA- Environmental Impact Assessment

IARC- International Agency for Research on Cancer

IDP- Integrated Development Plan

IWRM-Integrated Water Resources Management

MMA -Mines and Minerals Act

MPRDA -Mineral and Petroleum Resources development Act

NALEDI- National Labour & Economic Development Institute

NWA- National Water Act

NWRS-National water resources strategy

NEMWA-National Environmental Management: Waste Act

PITTs-Policy Implementation Task Teams

SANS-South African National Standards

Sv-Sieverts

UNEP- United Nations Environment Programme

UNESCO- United Nations Educational, Scientific and Cultural Organization

UNICEF- United Nations Children's Fund

WDM-Water Demand Management

WFS-Wonderfonteinspruit

WHO-World Health Organization

DEFINITION OF CONCEPTS

Radionuclides: Naturally occurring radioactive minerals that are occasionally present in bedrocks; they are also by-products of mining activities. Examples include uranium and radium, which in high concentrations result in toxicity to the kidneys and increased risk of bone cancer among other things.

Heavy metals: Metallic chemical elements, which have a relatively high density and are toxic and poisonous at low concentrations namely; cadmium, lead, chromium, arsenic *etc*.

Drinking water: Water meant for human consumption, which should be of sufficiently high quality so that it does not cause immediate or long-term harm to the public.

Health risk: A degree of likelihood that exposure to a particular contaminant will affect the health of the exposed population.

Catchment: An area drained by a river system.

Morbidity: The incidence/occurrence of diseases or conditions.

Informal settlements: Dense settlements comprising of communities housed in self-constructed shelters under conditions of informal or traditional land tenure.

AMD (Acid mine drainage): An outflow of acidic water from (usually abandoned) metal mines or coal mines, characterized by low pH, high acidity and a high concentration of toxic metals.

Water quality: The physical, chemical and biological characteristics of water.

Radiological annual dose: A measure of the average radiation energy received by the whole body measured in (Sv) assuming that uptake of a certain amount of radioactivity occurs in a year over the whole lifetime of a person and taking into consideration the sensitivity of a human body at different age intervals.

Isotopes: Different types of atoms (nuclides) of the same chemical element, each having a different number of neutrons. In a corresponding manner, isotopes differ in mass number (or number of nucleons) but not in atomic number.

Biological indicator: An organism which accumulates contaminants in its tissues in a way as to reflect environmental levels of those substances to the extent to which the organism has been exposed to them.

Water institution: A set of rules that define the action sets for both individual and collective decision making in the realm of water resources development allocation and utilization formalized in terms of the three aspects; water law, water policy and water administration

CHAPTER 1

1. INTRODUCTION

Water is one of the most essential components of the life systems and forms a basic part of the natural environment. Like many other resources, water exists in finite quantities and is being polluted at rates approaching totality, it is therefore necessary to use this essential commodity in a sustainable manner ensuring that the present generations can meet their demand without affecting the future generation`s ability to do the same. The availability of water is threatened by anthropogenic activities which have led to phenomena like climate change and pollution. These phenomena denote serious negative implications on the availability of sufficient potable water resources to drive the most basic uses of domestic consumption and industrial purposes. This chapter introduces the research (problem and objectives) and further highlights the connection between water resources management and the sustainable development concepts; also it covers the impact of mining activities on water resources and the resultant problems.

1.1 Water Resources and Sustainable Development

Development in the final lapse of the 20th century has taken a new twist that not only focuses on economic growth alone, but also, encompasses the aspect of environmental conservation in a new phenomenon termed 'sustainable development'. Sustainable development calls for balanced interrelated policies aimed at economic growth, poverty reduction, human welfare, social equity and protection of the Earth's resources (UNESCO, 2000). Water is a vital limited resource for human existence and the availability of water connects strongly with the sustainable development concept.

South Africa is faced with the problem of scarcity of fresh water resources and highly variable hydrological conditions leading to every major river in the country being regulated in order to ensure adequate water supply for development (NSER, 1999). Due to the spatial variability and scarcity of water resources in many catchments, the need for water exceeds the supply. The scarcity of water is further compounded by the deterioration in quality because of water pollution. Opperman (2008) forecasted that water will increasingly become the single most limiting resource in South Africa and supply will become a major restriction to the future of socio-economic development of the country. Four million people in South

Africa were reported to lack access to clean water in urban areas thus restricting economic growth.

The inverse side of the water scarcity issue involves the pollution of natural water systems like rivers and streams by anthropogenic activities which include mining, industrial activities and farming. Pollution of natural watercourses with mine drainage is a major environmental issue worldwide (Bhuiyan et al., 2010). A major problem related to mining in many parts of the world is uncontrolled discharge of contaminated water or decant from abandoned mines which is generally termed acid mine drainage (Banks et al., 1997a;b; Pulles et al., 2005). South Africa has a mining-based economy; however, the mining companies and the government have underplayed or ignored the social injustices and negative environmental impacts that accompany mining activities (Van Eeden et al., 2005).The semi-aridity of South Africa has led to the environmental impacts arising from mining, related to acid mine drainage beginning to show face after a century and this may continue to damage the environment for a thousand more years to come.

1.2 Challenges within the Wonderfonteinspruit Catchment – South Africa

As at 1997, South Africa produced an estimated 468 million tons of mineral waste per annum (DWAF, 2001). According to Oelofse et al., (2007), wastes from goldmines constitute the largest single source of waste and pollution in South Africa contributing up to 221 million tons or 47% of all mineral waste thus there is a wide acceptance that acid mine drainage (AMD) is responsible for the most costly environmental and socio-economic impacts. AMD emanates from both surface and underground workings, waste and development rock ,tailings piles and ponds (Durkin and Herrmann,1994).AMD is characterized by high acidic concentration of metals and metalloids which can create problems of groundwater and surface water pollution in the area of the mine (Bhuiyan et al., 2010). The generation of AMD can persist for hundreds of years after closure of the mine thereby jeopardizing water resources and causing deleterious effects on aquatic life and terrestrial environment (Demchak et al., 2004).

The Wonderfonteinspruit River flows between Gauteng and the upper North West province. The North West province is densely populated because of its agricultural value and the presence of gold mines. Mining forms an integral part of the economy, contributing approximately 74% of the employment in the area (North West Environmental Outlook Report, 2008). As a result, there are a growing number of communities located in the catchment including Kagiso, Mohlakeng, Toekamsrus, Rietvallei and Bekkersdal.

The headwaters of the Wonderfonteinspruit originate from the mine residue deposits of several old and abandoned mines of which these are significant contributors of the diffuse contamination. Numerous active gold mines are discharging fissure and process water into the environment. There is groundwater contamination of which the groundwater is discharged into streams. It is estimated that gold mines discharge 50 tons of uranium yearly into receiving watercourses. The mine effluent generated by the mines on the West Rand has a negative impact on the quality of groundwater because large portions of mine land in the Gauteng and North West and the rivers that flow from this land occur close to or on top of dolomite (Coetzee et al., 2006, Hobbs and Cobbing 2007). The rate of oxidation and dilution and the deleterious effect of the addition of contaminated water persist 10km beyond the source (Naicker et al., 2003).

1.3 Problem Statement

Surface and groundwater resources are of increasing importance as sources of water supply to a growing population. Groundwater is of importance in the North West province contributing up to 80% of water use in the rural and agricultural communities (North West Environmental Outlook report 2008). Many people and their livestock depend on the rivers and the groundwater from the Tweelopiespruit and Wonderfonteinspruit catchments (Oelofse et al., 2007). On farms, contaminated groundwater is used for livestock and to irrigate crops, which can eventually pose serious health problems to people eating this produce. Due to the presence of gold deposits in the area, a great number of informal settlements have erupted in the catchment. These informal settlements lack clean water (piped water systems/potable drinking water) giving rise to possible utilization of untreated surface and ground water for drinking and personal hygiene in the catchment.

Formal townships, which are also closely related to the mining activities in the catchment, abstract water from the boreholes for domestic use. Carletonville municipality abstracts a small portion of water from boreholes and Potchefstroom municipality abstracts water from the Boskop dam for domestic use. Farmers therefore risk losing their earning capacities due to the use of contaminated water .Long-term exposure to polluted drinking water has been shown to lead to increased rates of cancer, appearance of skin lesions and decreased cognitive function and heavy metals in drinking water strongly compromise the neural development of a foetus (Adler et al., 2007; Ahsan et al., 2006; Bellinger et al., 1992)

. Questions can thus be raised, regarding the safety of the drinking water for the public in the Wonderfonteinspruit catchment area, in both the formal and informal settlements, in terms of radionuclide and heavy metal contamination. It is in this light that this study seeks to determine the presence of radionuclide and heavy metal contaminants in drinking water sources within the Wonderfonteinspruit catchment and the health risks thereof.

1.4 Justification of the Study

Although extensively researched from a variety of academic angles and disciplines, the management of water affairs issues in the Wonderfonteinspruit catchment area still remains controversial and of tremendous concern (Van Eeden et al., 2005). Winde (2010) concluded that attempts to manage this catchment had been uncoordinated and fragmented, resulting in the current manifestation of environmental problems caused by impacts that have been continuing for many years.

Coetzee (1995) reported on the airborne gamma ray scan of the upper Wonderfonteinspruit and concluded that the Wonderfonteinspruit is an important transport line of radioactive material from gold mine slime dams. Winde (2000) analyzed sediment samples from the Wonderfonteinspruit catchment and concluded that although radionuclides and heavy metals were mostly trapped in the sediments they might possibly be mobilized under certain conditions like variations in pH, redox conditions and by resuspension of sediments during flood events.

There was a study commissioned by the National Nuclear Regulator (NNR) to determine the presence of radioactive contamination in the Wonderfonteinspruit catchment using fish and vegetable samples. Results indicated radiological levels above regulatory levels and suggested the possibility of heavy metal contamination (NNR 2005). Furthermore, there was a study where an assessment was done of sources, pathways mechanisms, risks of current and potential future pollution of water and sediments in gold mining areas of the Wonderfonteinspruit catchment (Coetzee et al., 2006).

In addition, in 2007, the National Nuclear Regulator performed a radiological risk assessment on the public in the Wonderfonteinspruit catchment area and published the radiological risks though the results were restricted to the public. At the core of all the rumours regarding environmental destruction and pollution are the health threats to informal settlements in the area and the irreversible harm done to water resources and the environment (Van Eeden et al., 2005). There have been monitoring programs, reports, forums and committees, which have not in any way ameliorated the impact upon the local communities.

It can thus be concluded that the contemporary research in this area to date was mainly concentrating on:

- radioactive contamination and the possible risks associated with that exposure and not heavy metals;

- contamination of water in general not specifically drinking water except in a study which was looking at the Mooi river catchment which includes the Wonderfonteinspruit catchment but the samples taken from the Wonderfonteinspruit were not representative of the whole catchment;

There has also been no effort to establish the drinking water sources, the water quality of those sources and correlations between the presence of these contaminants in water and the occurrence of the health risks associated with these contaminants amongst people living in the catchment area. Winde (2006) concluded that there had not been any investigation aimed at establishing possible health implications in affected communities that had been conducted in the Wonderfonteinspruit by 2006. In addition, the only health related concerns that are currently addressed by the legislation, pertain to occupational health and safety of mine workers ignoring the off-mine populations who are usually affected by pollution from upstream activities (Adler et al., 2007).

1.5 Objectives of the Study

Therefore, the purpose and main objective of this study was to identify the link the environmental pollution in the Wonderfonteinspruit and the health effects arising thereof.

The specific objectives included:

- To identify the drinking water sources for formal and informal settlements in the Wonderfonteinspruit catchment;

- To establish the levels and variations of uranium isotopes and heavy metals namely cadmium, arsenic ,zinc, cobalt and lead in drinking water sources and explore possible risks of the contaminated drinking water,

- To establish community perceptions and awareness regarding water quality management issues,
- To examine the effectiveness in the implementation of institutional set-up for water resources management in the area.

The Main Hypotheses:

H_0: There are no radionuclide and heavy metals in drinking water sources in the Wonderfonteinspruit catchment area,

H_0: There are no health risks from radionuclides and heavy metals in drinking water sources in the Wonderfonteinspruit catchment area

H_0: The quality of water and its availability have no effect on the perceptions of the Wonderfonteinspruit catchment communities regarding water management in the catchment

H_0: The implementation of institutional set-up for water resources management in the WFS catchment is not effective

Research Questions

The Research seeks to answer the following questions

1. What are the main and alternative water sources in WFS catchment?
2. Is the water from all the drinking water sources safe for human consumption?
3. What are the levels and variations of Uranium isotopes and heavy metals in drinking water sources?
4. Are there any health risks associated with the drinking water sources in the catchment?
5. What is being done to ensure that there is adequate potable drinking water for all the people in the catchment?
6. How effective are the efforts in place to provide adequate potable drinking water in the catchment?
7. What are the community perceptions regarding water supply, quality and management in the catchment?
8. Is the institutional set up for water resources management in the area effective?

1.6 Description of the Study Area

The Wonderfonteinspruit (WFS) River is located between latitude 28° 53' 0"and longitude 25° 48' 0", and runs 90km from the outskirts of Johannesburg to the south west, past the towns of Krugersdorp, Bekkersdal, Carletonville and Khutsong, and flows into the Mooi river near Potchefstroom. The towns are located in the three municipalities within the catchment namely: Merafong, Mogale and Westonaria. There are more than 400 000 people residing in and around the area (Tempelhoff, 2007). The catchment is divided into two sections: the upper section, which commences in the Gauteng province in Krugersdorp (Tudor dam) to Donaldson dam in Bekkersdal and the lower section, which lies in the North West province from Bekkersdal to Carletonville before flowing into the Mooi River. The catchment covers a surface area of 460.94 km^2; a mean annual precipitation of 663.5 mm with a reported mean annual run-off into surface streams of 29.5mm (Midgley et al., 1994).

1.6.1 Study Area

The main aim of the study was to look at the WFS River entirely, thus four settlements along the river were selected, taking into consideration that they were supposed to be representative of the whole catchment's characteristics, comprising of the upper and lower sections. The four settlements included Kagiso, Khutsong, Bekkersdal and Carletonville and a brief description of each municipality were these towns fall is given below.

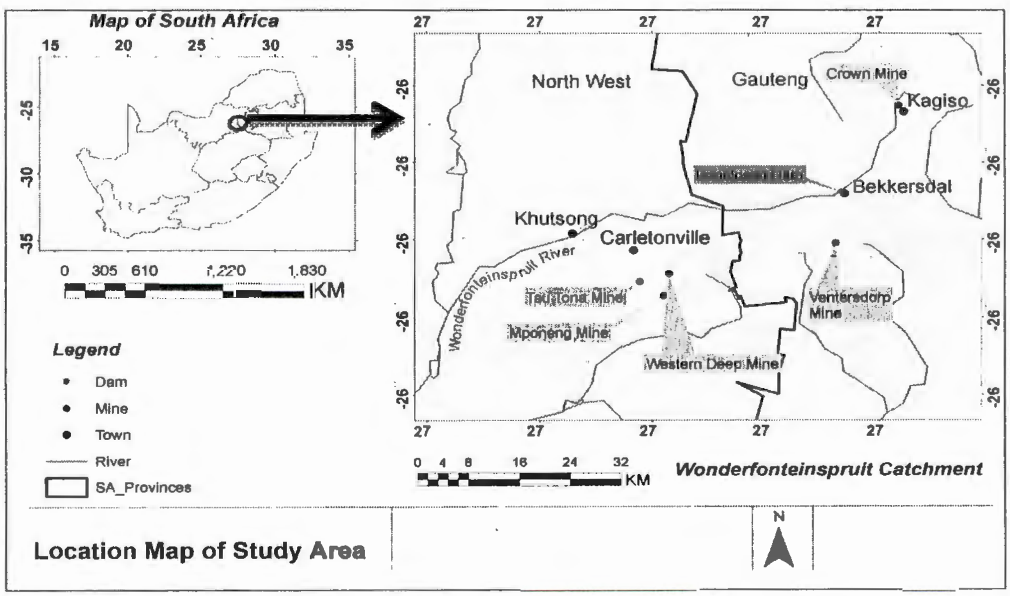

Figure 1: The map of the Wonderfonteinspruit catchment

Merafong

This is the municipality for Carletonville and Khutsong; but there are also other settlements which have not been included in this study which include Fochville, Welverdiend and Oberholzer. The population in Carletonville, the administrative town for the municipality, is 28 090 with 326 informal structures and Khutsong has a population of 149 850 with about 13000 structures as per the National Census 2001 (Merafong City, 2008). The main economic activities in the area are mining and agriculture with the former, contributing to about 67% of employment in the area and contributing approximately 69% to the economy of the area. Agriculture on the other hand employs 0.9% of the population and contributes around 1.1 % to the local economy (Merafong City, 2008). The agricultural activities are conducted on the peripheral of the urban areas as well as next to the WFS River where many small scale livestock and crop farmers are notable.

Mogale

The municipality is located on the western borders of the Gauteng Province. This municipality boasts of the Cradle of Humankind World heritage site which is also found within. The total population in the municipality is 223 657 as per 1996 census. Gold mining used to be at the core of the economy in that area, although there has been a major shift in the focus to include agriculture and manufacturing. Kagiso, which is part of the study area, has a population of 190 000 and it lies close to other settlements like Rietvallei and Azaadvillle which have also been used in this study due to their close proximity to the WFS river.

Westonaria

Table 1: Total population, Westonaria Source: NALEDI, (2004)

Settlement	Census 1996		IDP 1998		BURP 2004	
	Houses	No. of people	Houses	No. of people	Houses	No. of people
Informal	13 447	44 676	8 400	50 400	9 032	26 283
Formal	1 200	4 800	1 800	9 000	1 695	7 485
Backyard shacks	2 351	7 806	5 000	30 000	3 668	10 600
Total	**16 998**	**57 282**	**15 200**	**89 400**	**14 395**	**43 568**

This municipality is situated in the West Rand of the Gauteng Province 20.31679 latitude and 27.65 longitude .The total population size for this municipality is approximately 156 598 and it consists of about ten suburbs of which Bekkersdal is among them. Some of the land use activities are agriculture and mining constituting 3.79% and 3.32% respectively. The majority of households in the area have access to piped water, with 28% and 30% access recorded for the rural and urban populations respectively.

1.6.2 Geology

The catchment is characterized by karst subsurface geology underlain by dolomitic aquifers, which at one point, contained copious volumes of water. Gold mining activities led to the dewatering of some of the aquifers, which led to the lowering of the water table, and the subsequent formation of dolines and sinkholes. The dolomitic underground is divided into several compartments separated by impermeable vertical syenite dykes. Geological faults and dykes as well as sinkhole have historically been known to channel pollutants to underground water resources. The shifting of the water table to its original position has caused the decanting of an effluent rich in heavy metals.

1.6.3 General Socio-Economic Aspects

Some of the richest, largest and deepest (4 km) gold mines in the world for example, the Harmony gold mines; the fifth largest gold producer in the world, have operations in the Wonderfonteinspruit catchment area. The gold bearing reefs contain an array of minerals such as native gold, uranium oxides, traces of platinum and an array of sulphide minerals with pyrite being the most abundant.

Farming and large-scale mining are the predominant land uses. Downstream farmers have been adversely affected by the dropdown of the water table due to dewatering. The majority of the inhabitants live in the informal settlements using contaminated ground and stream water for personal hygiene and drinking.

Liefferink (2010) reported that since the Wonderfonteinspruit area has above average infection rates of HIV/AIDS and chronic and acute malnutrition, it is thus particularly more vulnerable to additional stress of the immune system by contaminants such as uranium

1.7 Research Ethics

This research was carried out guided by the four main ethical principles; respect and protection, transparency, scientific and academic professionalism and accountability.

1.8 Organization of Chapters

Chapter one is an introduction laying the foundation to the study, comprising of the background and rationale, the objectives of the research as well as a comprehensive detail of the study area. Chapter two which is literature review, documents studies and findings from research related to the study; aspects of heavy metal and radionuclide contamination in water at global, regional and local scales. Water related government publications are also discussed. Chapter three, which entails the research methodology looks mainly at the research design and the methods of data collection, sampling procedures and the materials that were used. Chapter four comprises of results and discussion on the water sources and water quality presented in the form of tables, graphs, pie charts and histograms, and also statistical tests which were used to illustrate the relationships between the different variables. Chapter five consists of results and discussion on community perceptions and the water institution in South Africa. Chapter six is the conclusion and recommendations, consisting of a summary of the whole research as well as suggestions on remediation measures for water pollution and water resources management. Appendices: includes questionnaires and interview questions as well as statistical analysis and letters for data collection.

1.9 Limitations to the Study

South Africa being a multicultural country has different tribes with different cultures and in particular, languages, which meant that, the researcher had to have multi language proficiency. This resulted in the use of a translator during some interviews in the study where there were languages barriers leading to the accuracy of the information being compromised, but because the questionnaire had straight forward questions and structured answers it made it easy, for the translator to interpret, the questions and the respondents to answer the questions. The translator was also trained to understand what the questionnaires required.

Also the participation of mines of was not overwhelming as only one mine agreed to be part of the survey, but because the main focus of the research was on the health risks, the results of this research were not affected in any way.

Due to logistical problems and funding, the water samples for the wet season were collected at the end of the wet season which might have a bearing on the results presented in the research. Nonetheless, due to the shift in the seasons and climate changes, rains were still being experienced during the time of sampling.

Summary

It is evident that water is a vital limited resource which not only drives sustainability but functionality of the ecosystems. The human elements of the ecosystem, in this case the Wonderfonteinspruit catchment communities; face a major threat on their health. In order to achieve the main aim of the study, there was therefore a need to ascertain, the possibility of river use for domestic consumption and consequent risks. The following chapter documents the various impacts of acid mine drainage on the water resources and subsequently, the health effects arising from consumption of contaminated water. The information presented thereof derives from various studies around world.

CHAPTER 2

2 LITERATURE REVIEW

This section discusses the problems of water scarcity and pollution globally, regionally and nationally. Existing research on generation of acid mine drainage, its environmental impacts and health effects of contaminants in drinking water are also covered in this chapter. A comprehensive discussion on the water institution implementation in South Africa concludes the chapter.

2.1 Water Supply and Quality

Access to clean water is universally accepted to be a precondition for economic and social development (Molden and Merrey, 2002; Gilbert et al., 1996). This is because the relationships between water availability, water demand, *per capita* consumption and the standard of living are directly proportional to each other, with an increase in any one of these factors also having a negative bearing on the economy. Freshwater is scarce and resources are unevenly distributed throughout the world with much water located far from the human populations (Güler, 2007). UNEP (2002) reported an approximate of 450 million people in 29 countries suffering from water shortages and that water related concerns are the most acute in arid and semi-arid areas.

The inverse side of water supply, that is water scarcity, consequently involves water pollution. Due to anthropogenic activities, freshwater systems are confronted with thousands of compounds (Schriks et al., 2010). Johnson and Hallberg, (2005) stated that in 1989, it was estimated that an approximate 19 300km of streams and rivers and about 72 000ha of lakes and reservoirs worldwide, had been seriously impacted by mine effluents. It is however somewhat difficult to measure the current magnitude of the environmental pollution, thus continuous discharge of effluents and associated toxic compounds into aquatic systems represents an ongoing environmental problem (Keller et al., *2002*). This is due to their possible impact on communities in the receiving aquatic end and a potential effect on human health (Adler *et al.*, 2007).

On a regional scale, Africa faces major challenges relating to the access to basic sanitation and sufficient potable drinking water. The problem is not only confined to rural areas but is a common issue across various communities in urban areas in developing and underdeveloped countries. Falkenmark (1989) reported that there was an urgent need for increased awareness among African leaders so that adequate strategies can be made for development under conditions of severe water scarcity. Availability of water improves self-sufficiency; in particular, food production and other water dependent societal activities. Falkenmark, (1989) maintained that there are a few, if any, models that can be followed for socio-economic development for Africa under severe water scarcity. There are projections suggesting absolute water scarcity in Malawi and South Africa by 2025 and water stress for Zimbabwe, Mauritius and Tanzania (Hirji et al., 2002). The Southern African Development Corporation (SADC) is making headway in the search for initiatives aimed at sustainable development. To achieve this, SADC's main goal is to achieve the sustainable utilization of natural resources and effective protection of the environment (Hirji et al., 2002). Although there have been major policy shifts to attain this ,more needs to be done to have operationally effective policies as well as institutional framework that reflect effective integration of sustainable management principles (Imperial, 1999).

2.1.1. South Africa's Water Stress Profile

South Africa is a water stressed country (Turton, 2003). The water supply and demand situation in the country may look comfortable but the seasonal and regional variations in rainfall and the cyclical patterns as well complicate the national water balance (Backeberg 2005). Only 8.6% rainfall is available as surface water (Davies and Day, 1998) and the mean run off pegged at 49,228 million m^3.Hamann and O'Riordan, (2002) argued that water scarcity is a socially constructed notion and the argument was based on the fact that, approximately 20 million black South Africans experience water shortages and or do not have access to water and basic sanitation. On the contrary, white South Africans use as much as they need and more. Karr and Dudley, (1981) stated that it was imperative for South Africa to develop a water efficient economy together with a social ethic of water conservation and ultimately a culture of sustainability of water resource use. Predictions indicate that beyond 2020, South Africa will have no water to spare if all black South Africans are adequately provided with water (Davies and Day, 1998). Consequently, every major river in the country ought to be regulated in order to ensure adequate water supply for development (NSE Report, 1999).

In addition, the scarcity of water is further compounded by the deterioration in quality because of water pollution. Pollution of natural watercourses with mine drainage is a major environmental issue worldwide (Bhuiyan et al., 2010). About 6 billion tons of tailings have been produced in Witwatersrand, ever since the commencement of mining activities a century ago (Janisch, 1986; Robb and Robb, 19998a, b; Wymer, 2001). Winde and De Villiers, (2002) reported that an approximate 6000t of U are annually deposited into slimes dams by gold mining activities in South Africa. The WFS runs through two goldfields, *i.e.* the West Rand and the Far West Rand, of which tailings from these two are estimated to contain over 100,000tons of U creating a large reservoir for ongoing future pollution (Winde, 2010).

The *status quo* of the environment in the WFS catchment can be attributed to the negative externalities that were not incorporated within environmental planning and management systems during the apartheid era (Adler et al., 2007). Thus, the mining industry failed to adequately prepare for closure and to dispose off mine waste in a manner that is consistent with current international best practice. Cumulative harm to off mine populations resulting from modified water tables, contaminated groundwater sources, acidic mine drainage and ground instability must be addressed before they lead to an even more devastating socio-economic, political and environmental damage (Adler et al., 2007). Recent reports concerning the polluted mine water spillages into the environment have been highly politicized, thereby creating strong sentiments about the relationship between the mining industry and the government (Adler and Rascher, 2007). The WFS catchment has a surface area of approximately 460.94km^2 making AMD an extraordinary problem of spatial dimensions (Tutu et al., 2008). In addition, long-term effects on cattle and crop farming and established drinking water supplies are also of concern as shown by a number of recently launched projects (Hearne and Bush, 1996; IWQS, 1999; Wade et al., 2002).

2.2 Mining, pollution and health

Mining has potentially adverse impacts on the natural environment, society and cultural heritage, the health and safety of mine workers and communities based in close proximity to the operations (Moody and Panos, 1997). In a study assessing the socio-economic and environmental impacts of mining in Tanzania, findings included: the effects of mining on the environment, the release of many chemical contaminants into water resources, environmental damage that can persist for a long time after mine closure and the health and safety of nearby communities being compromised (Kitula, 2006). Other contaminants are sulphates resulting from the mining processes, which originate from the oxidation of the sulphides in the ore that may result in the acidification of water and the consequent mobilization of the above-mentioned metals including Uranium series radionuclides that occur at elevated levels within the ore. People are becoming aware of the delicate balance and the complexity of nature that exists within the global ecosystem (Ahmet et al., 2006). Consequently, though the mining population maybe attracted by the economic benefits they also worry about the potential implications on their livelihoods, consumption, well-being and health (Bebbington and Williams, 2008). Noronha (2001) indicated that the social and environmental impacts of mining are more pervasive in regions where operations are newly established or are closing down. The following section looks in detail at AMD which is the most fatal by-product of mining operations.

2.2.1 Acid Mine Drainage (AMD)

Acid mine drainage probably presents the single most important factor in dealing with tailings and waste rock and their impact on the environment (Ritcey, 2005). AMD is produced when sulphide bearing material is exposed to oxygen and water resulting in low quality effluents. Exponential growth in the surface area of the ore exposed to air occurs which corresponds to the rates of chemical reaction and thus the release of contaminants into the environment (Berkowitz et al., 2006). The production of AMD usually does not exclusively occur in iron sulfide, but also copper, nickel and other sulfide-rich rocks aggregated rocks. There are some main chemical reactions which illustrate the weathering of pyritic rocks resulting in the formation of AMD (Evangelou and Zhang, 1995);

$2FeS_2 + 7O_2 + 2H_2O \longrightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$

Pyrite +Oxygen+ Water $\longrightarrow$ Ferrous iron + Sulphate +acid q 1)

$4Fe^{2+} + O_2 + 4H^+ \longrightarrow 4Fe^{3+} + 2H_2O$

Ferrous iron+ Oxygen +Acidity $\longrightarrow$ Ferric Iron + water (2)

$4Fe^{3+} + 12H_2O \longrightarrow 4Fe(OH)_3 + 12H^+$

Ferric iron +Water $\longrightarrow$ Ferric Hydroxide + Acidity (3)

$FeS_2 + 14Fe^{3+} + 8H_2O \longrightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$

Pyrite+ Ferric iron+ Water $\longrightarrow$ Ferrous Iron+ Sulphate+ Acidity (4)

Overall reaction summarized

$4FeS_2 + 15O_2 + 14H_2O \longrightarrow 4Fe(OH)_3^- + 8H_2SO_4$

Pyrite + Oxygen +Water ⟶ Ferric Hydroxide + Sulphuric Acid (5)

Releases of AMD have low pH, high electrical conductivity, elevated concentrations of anions (sulphates), Fe, Al, Mn and raise the concentrations of toxic heavy metals (As, Cd, Cu, and Zn) (Tutu et al., 2008). The acid produced dissolves salts and mobilizes heavy metals from mine workings. Briefly, AMD introduces acidity due to its low pH, leading to metal toxicity emanating from metal dissolution, also salinization as a result of the dissolution of salts. This results in impacts which range from non-detectable to completely destructive on the flora and fauna (Kelly, 1988; Gray, 1997; Cherry et al., 2007; De Nicola and Stapleton, 2002; David, 2003). AMD is not only associated with surface and groundwater pollution, but is also responsible for the degradation of soil quality, for harming the aquatic sediments and fauna and for allowing heavy metals to seep into the environment (Adler and Rascher, 2007).

The environmental implications of tailings disposal include contamination of streams by AMD, contamination of streams due to surface run off from the impoundment area, air and water contamination due to wind erosion of dried out tailings. It also leads to possible risks of catastrophic dam failure and release of slimes; physical and aesthetic modification to the environment and difficulty of establishing vegetative cover to permanently stabilize the tailings, due to unfavorable soil conditions in the presence of pyritic tailings (Oelofse et al., 2007). AMD follows the same flow pathways as water and therefore it can be controlled by controlling water entry into the site of acid formation by diversion of surface water away from the residue storage areas, prevention of hydrological seepage into the affected areas and controlled placement of acid generating waste (Akcil and Koldas, 2006). Thus, offsite pollution by eroded slime particles can be prevented relatively easily and cost effectively. The same is not true for the aqueous pathways as experienced with rehabilitation of Uranium mining sites in the US (Robinson, 1995) and in Germany (Winde, 2000).

2.3. Environmental Impacts of Acid Mine Drainage

There is a lot of research internationally as well as locally on the environmental impacts of abandoned and active mining activities, with AMD being classified as the most adverse to the environment especially on water resources (Adler et al., 2007). Witman and Forstner, (1976) observed enrichment of metals in streams draining the Central Rand. Marsden, (1986) further probed this concept and reported on elevated concentrations of heavy metals in the streams around the Central Rand which were in the vicinity of gold mining tailings dumps. In a similar study, Jones et al., (1988), attributed this steady rise in metal concentrations to the mining activities in proximity to the area. The movement of these trapped metals from underneath the tailings is due to the dewatering activities.

Rösner and van Schalkwyk, (2000) and Rösner (2001), indicated that even decades after decommissioning and clearing of mines, significant loads of salts, metals and radionuclides remain trapped beneath reclaimed tailings. Coetzee (1995) did an airborne gamma ray scan and concluded that the WFS is an important transport line of radioactive materials from the mines' tailings to the other water sources within the catchment such as the Mooi river loop which is also part of the catchment. Hearne and Bush, (1996) and Winde, (2001) suggested that seepage containing high concentrations of dissolved contaminants migrates from tailings deposits into sub-adjacent aquifers and finally enters adjacent streams. Naicker et al., (2003), further demonstrated this in a study of groundwater seeping from disused tailings. The study reported that mining activities contaminate shallow ground water hence contributing to the quality of surface water emanating from the Witwatersrand catchment. Besides, contaminants not only affect the pH of water, but also contribute heavy metals to the surface environment, constituting about 20% of surface stream flow (Naicker et al., 2003). The movement of these contaminants in and near mining sites is a function of geology, hydrology, geochemistry, pedology, meteorology, microbiology, and mining and mineral processing history (Nordstrom and Alpers, 1999).

Davidson, (2003) illustrated that water quality in the Witwatersrand basin deteriorates in the proximity of mine tailings and improves in the distal regions, and this has been largely attributed to the presence of wetlands which act as sinks and traps for pollutants (McCarthy and Venter ,2006). This is in agreement with Winde, (2000), who noted a decrease with distance of radioactive levels in a study on the WFS catchment. Although contaminant concentrations decrease with distance in the water column, the same is not true for sediments which have been shown to trap contaminants, suggesting solute transport mechanism which conforms to U concentrations in the range of 50- 90 ppm in the lower WFS sediments as compared to concentrations in the range of 0.02-0.14ppm in the water column (Winde, 2000).

Furthermore, Naicker et al., 2003, reported that the effects of contaminated water persists for considerable distances downstream the pollution sources. This is attributed to the slow rates of dilution and oxidation of iron which acts as buffer thereby controlling the pH, and facilitating the removal of metals from the water column. Although it was suggested that the water column toxic metal concentrations can be maintained at a safe level while the sediments become enriched with respect to metal concentrations (Wade et al., 2002; Winde, 2000), the 30x enrichment factors (Winde ,2000) for U are a cause for concern. U concentrations have radiological and chemical toxicity especially through the domestic consumption of the water. There is also evidence from recent studies which indicates the occurrence of health risks at lower than previously reported concentrations of U in drinking water (Kurttio et al., 2002) (Section 2.4).

The stream water pollution not only depends on the concentration of pollutants but also on the rate at which polluted groundwater infiltrates the stream (Winde and Van der Walt, 2004) as well as the seasonal variations. The rate of groundwater infiltration is supposed to be high during the rainfall seasons because of the rise of the water table, thus resulting in more stream water contamination (Tutu et al., 2008). At the same time, the quality and intensity of the rainfall further affects the mobilization of U, since acidic rainfall introduces acidity to the streams (Winde and van der Walt, 2004). Rösner and van Schalkwyk (2000) reported on contamination of soil profiles in the proximity of tailings in particular the top soil, with heavy metals Zn, Co and Ni. The top soil contamination was attributed to evaporation and capillary rise of groundwater from the vadose zone (Naicker et al., 2003). The resultant heavy-metal enriched crust is a secondary source of pollution to groundwater sources, and since these metals exist in a labile form, they can thus been reintroduced into groundwater by leaching (Rösner and van Schalkwyk, 2000). In another study on health effects and environmental impacts of trace metals and radionuclides (Van Hook, 1979), it was noted that the trace metal concentrations in soil decrease rapidly with distance from power plants approaching background levels at distances > 3km from the coal plants. The contamination of the soil has largely been attributed to upward and lateral movement of water and solutes within the soil, when soil surface evaporation and plant transpiration exceed rainfall infiltration.

The metal distribution in rivers is controlled by pH, with an increase in pH resulting in co-precipitation and or adsorption of metals primarily with secondary Fe hydroxide minerals (Boult,1996; Banks et al., 1997a;b;Young ,1997) which will result in the alteration of metal load potentially allowing storage in an insoluble form within the receiving wetlands (Boult 1996). Other factors also controlling the metal distribution include the redox conditions and the resuspension of sediments during flood events (Thuy Nguyen, 2008). Physical factors, which affect metal retention and mobility in aquatic systems, include redox potential, pore space, and chemical transformations (Thuy Nguyen, 2008).

The contamination of streams by adjacent slimes dams poses a severe risk to the health of people in informal settlements, where polluted stream water is often consumed without appropriate treatment (Winde, 2000), as well as to the inhabitants within the catchment who are heavily reliant on groundwater for domestic consumption and personal hygiene. In addition, subsistence farming is often the sustaining land use activity in the informal settlements; consequently, the AMD can render the water unfit for agricultural purposes (Warhurst and Noronha, 2000). Also considering the fact that the contaminants are likely to have a coupled effect on human health and water quality impairment, drawing from the heavy metals as well as the U series decay radionuclides, the synergistic effects will almost certainly be greater (Brugge et al., 2011). This is supported by results from a study where algae were used to illustrate that U toxicity increased with the presence of Cd (Henner, 2008). Locally, a study in the Northern Cape in 1997 has linked the hematological abnormalities to the naturally elevated levels of U in domestically used groundwater (Toens et al., 1998). These health effects are discussed in greater detail in Section 2.4.

2.4 Health Effects of the Contaminants in Drinking Water

The major contaminants resulting from mining activities in the WFS catchment under study are radionuclides and heavy metals. The radionuclides include isotopes of radium and U, the former, poses a double threat from both toxicity and damaging radiation (Campbell, 2009) and gives off other by-products such as radioactive polonium and lead. Oxidation of radionuclides is a major concern for the natural environment because U for example, in the higher oxidation state of +6 is highly toxic and can thereby cause detrimental effects to the health of human and aquatic life and the quality of surface and groundwater used for drinking, recreation and crop irrigation (Krieger, 2005). Heavy metals like lead for example, may adversely affect the nervous system and kidneys (Mugica et al., 2002). This section comprises a detailed account supported by literature of various health effects arising from contaminated drinking water and in particular, with heavy metals and radionuclides.

2.4.1 Heavy Metals

Reports on exposure to heavy metals reflect an ongoing increase in many parts of the world particularly in the developing countries although several adverse health effects resulting from the heavy metals are known. Exposure to metals is a cause for concern since they possess the potential toxic effect and ability to bio-accumulate in aquatic ecosystems (Miller et al., 2002; Censi et al., *2005*). Many metals like Cd and Pb have no known physiological activity but they are proved detrimental beyond a certain limit (Marshner, 1995; Bruins et al., 2000).

Several studies have revealed that long term use of acidic heavy metal-laden mine water could cause the contamination of groundwater and agricultural soils, thus threatening the health of people who consume drinking water and food derived from such contaminated land systems (Chen et al., 2007). In aquatic systems, metals are present as dissolved ions complexes and colloids ions and solid in sediments with the concentrations heavily dependent on the biological processes, redox potential, ionic strength, pH, activities of chelators and scavenging processes (Larocque and Rasmussen, 1998). Järup, (2003) suggested that the main threats to human health from heavy metals are associated with exposure to lead, cadmium, mercury and arsenic. Schriks et al., (2010) concluded that although the health effects of many emerging contaminants present in the water cycle and the potential health concern associated with direct ingestion have been evaluated the statutory standards were not available.

A broad spectrum of effects, varying from shortness of breath to different types of cancers may occur, in the event of ingestion of drinking water containing significant amounts of trace metals (Cantor, 1997; Barwick et al., 2000; Xia and Liu, 2004; Dogan et al., 2005). The deadlier diseases like edema of the eyelids, tumor, congestion of nasal mucous membranes and pharynx, gastrointestinal ,muscular, reproductive, neurological and genetic malfunctions caused by some of the metals have been documented (Johnson, 1998; Tsuji and Karagatzides, 2001; Abbasi, et al., 1998). In other studies relating to exposure of pregnant women to relatively low concentrations of heavy metals and other industrial chemicals in drinking water results have revealed that the neural development of fetuses can be compromised resulting in the mental retardation of the offspring (Grandjean and Murata, 2007; Grandjean and Landrigan, 2006; Bellinger et al., 1992). It is therefore safe to conclude that monitoring of these metals is pertinent for not only the safety of the environment but also for the safeguarding of human health. The following sections are a comprehensive discussion based on the existing literature of the health effects arising from the heavy metals covered in the present study, which include arsenic, cadmium, zinc, lead and cobalt.

Carcinogenic Classifications

Table 2 shows the classification of carcinogens by the United States Environmental Protection Agency (USEPA) 2005. These descriptions are continuously made use of in the text.

Table 2: Classification of Carcinogens (USEPA 2005)

Group	Type of Carcinogen
A	Human Carcinogen (sufficient evidence if carcinogenicity in humans)
B	Probable human Carcinogen
B1	Limited evidence of carcinogenicity in humans
B2	Sufficient evidence of carcinogenicity in animals with inadequate evidence in humans
C	Possible human carcinogen (limited evidence of carcinogenicity in animals ,absence of human data)
D	Not classifiable as to human carcinogenicity
E	Evidence of non-carcinogenicity for humans (no evidence of carcinogenicity inadequate studies

Arsenic (As)

One of the most hazardous trace metals found in drinking water that is both toxic and carcinogenic is arsenic. Scientists the world over face a major and common challenge of adverse health effects arising from arsenic in drinking water (Chatterjee et al., 1995; Chowdhurry et al., 2000; Jain and Ali 2000; Mandal and Suzuki 2002; Jack et al., 2003; Ahmad et al., 2004; Arain et al., 2008). Arsenic is a naturally occurring element present in both inorganic and organic forms and in different environmental and biological samples (Villa-lojo et al., 2002). Arsenic is amongst the priority elements associated with AMD especially from gold mining operations. Inorganic arsenic is acutely toxic, intake of large quantities leads to gastrointestinal symptoms, severe disturbances of the cardiovascular, and central nervous systems and eventually death (Järup 2003). An evaluation by the WHO concluded that arsenic exposure via drinking water is causally related to cancer of the lungs, kidney bladder and skin. Drinking water concentrations of approximately 100μg/l have led to cancer and precursors of skin cancer have been reported at levels of <50µg (WHO, 2000). The drinking water standards set up by WHO currently permit not more than 10ppb of arsenic in drinking water (Järup, 2003). In an investigation of trends in infant mortality between two geographic locations in Chile, one area with a known history of an exposure to contaminated drinking water and one with low exposure indicated a possible role of arsenic exposure in increasing the risk of late fetal and infant mortality (Hopenhayn-Rich et al., 2000). There is also evidence, which denotes the association between arsenic ingestion and cardiac and cerebrovascular diseases as well as diabetes mellitus (Tseng et al., 2000).

Prior to the above mentioned study, a survey in India West Bengal on arsenic contamination of groundwater hinted at consumption of arsenic concentrations above the permissible limits recommended by WHO (Mandal et al., 1996) which was pegged at 0.05mg/l. Reports of arsenic contamination in especially groundwater have emanated from other areas; Taiwan, Chile, Argentina, Mexico and Thailand (Rana, 2006), though India is recorded to have faced the biggest arsenic calamity so far.

The effects of arsenic are known to show face in at least six months to two years or even up to between 8-14 years as indicated by Murkherjee et al., (2005). The time span for symptoms of toxicity to manifest depends on the consumption patterns, concentrations of the metal in the drinking water, the nutritional status and immunity level of the consumers (Mazumder et al., 2000). On the skin, the effects vary from darkening of the skin, spotted pigmentation, white and black spots as well as rough and dry skin in severe arsenic poisoning cases.

Cadmium (Cd)

Having an extremely long biological half-life to humans of more than 15 years (Alcock, 1996; Jin et al., 1998; Viaene et al., 1999), Cd is known to be potentially dangerous at global, regional and national levels. It is a cumulative toxic metal thus it accumulates in the renal cortex and may cause renal dysfunction at concentrations between 200 and 300rmugg^{-1} – (radius per couric mugs) wet weight (Ryan et al., 1982). After consumption, only a very small fraction of Cd is excreted and the total body content increases with age (Bender and Bender, 1997). Recent data suggests that adverse health effects of Cd exposure may occur at lower exposure levels than previously anticipated primarily in the form of kidney damage but also bone effects and fractures (Buchet et al., 1990; Järup et al., 2000). Hellstrom, (2001) revealed an association between Cd exposure and chronic renal failure [end stage renal disease (ESRD)]. Cd is also classified by the International Agency for Research on Cancer (IARC) as a human carcinogen (Table 1). Järup et al., (1998) states that Cd is a risk factor for osteoporosis which also aligns with the notion of disrupted calcium metabolism. Furthermore reports from Japan indicated that long term high Cd exposure may cause skeletal damage. Other effects include lung diseases and thyroid gland malfunction (Jin et al., 1998).

Cobalt (Co)

Significant knowledge exists concerning the genotoxic properties of Co and the potential mechanisms of action. There is also evidence to the effect that mutagenicity, toxicity, carcinogenicity can be observed after exposure to Co, variations occurring with species of the Co (Lison et al., 2001). Several reports illustrate that long-term consumption of Co in drinking water may result in dermatitis, asthma and cardiovascular failure for concentrations in the range of 5-10μg/day (Barceloux, 1999; Nordberg, 1994). According to Lauwerys and Lison, (1994), the skin and the respiratory tract are the target organs for Co.

Zinc (Zn)

Zn is an essential element for humans but in excess, it can be harmful. Fosmire, (1990) reported that an excess intake of Zn has resulted in induced copper deficiency, anaemia, and nuetropenia and impaired immune function. Zn is also listed as a priority pollutant. In the environment, Zn has been largely associated with impairment of river and stream water quality. Other human health impacts of Zn reported include nausea, fainting, and stomach disorders (Ntengwe and Maseka, 2006).

Lead (Pb)

Lead toxicity causes many diseases which include hematological, gastrointestinal and neurological dysfunctions (Lockitch, 1993). Pb in blood is bound to the red blood cells and can be slowly eliminated through the urine. If absorbed in the skeleton it will take even longer to be eliminated since the half-life is 20-30 years compared to the one month in the blood. Long term exposure to low level Pb has been shown to cause diminished intellectual capacity in children and may adversely affect the nervous system and kidneys (Mugica et al., 2002). More susceptibility is found in children compared to adults because the formers' intestinal absorption capacity is five times greater than the latter (Hettiarachchi and

Pierzynski, 2004). Acute exposure has been shown to cause proximal renal tubular damage (Järup, 2003). In 1987, the IARC classified Pb as a possible human carcinogen.

2.4.2 Radionuclides

Uranium (U)

U is non-biodegradable and therefore tends to accumulate in the biosphere reaching concentrations in soil, sediments and biota well above the natural backgrounds (Winde, 2003). Of all the heavy metals, U has the highest geochemical mobility in aquatic environments. The U decay series releases primarily alpha radiation along with some gamma radiation. It has a half-life of 4.5 billion years and can persist in the human body for varying lengths of time depending on the affected organs and various exposure pathways. The toxicity of U is as a result of its radioactive and chemical properties (Brugge et al., 2011; Taylor and Taylor, 1997). However, several studies have indicated that the major health effect of U is chemical kidney toxicity, rather than a radiation hazard (Wrenn et al., 1985; Leggett, 1989; Taylor and Taylor, 1997). The primary health outcomes of concern documented with respect to U are renal, developmental, reproductive and DNA damage, as well as diminished bone growth, these were derived from experimental animal studies and human epidemiology. The primary routes of entry into the body include ingestion and inhalation. In a study on the health of residents living near a U processing plant in the United States, were a reported 99 000 kg of U was cumulatively released to surface water, Pinney et al., (2003) reported a statistically significant elevation of the urinary systems diseases, which included bladder and kidney disease, kidney stones and chronic nephritis.

Studies mainly looking at the association between U and cardiovascular diseases have found no association except in a study amongst workers in Ohio at a U processing plant (Pinney et al., 2003). There is also sufficient evidence to suggest that U is an endocrine disruptive compound (EDC) (Raymond-Whish et al., 2007), mimicking the effect of oestrogen, thus increasing the risk of fertility problems as well as the occurrence of reproductive cancers (Winde, 2010). U has been reported to be immunotoxic in a study in which chicken lymphocytes were exposed to low concentrations of uranyl nitrate, thereby compromising the human immune system. This therefore exacerbates the situation for residents in the WFS catchment in particular Carletonville which was dubbed to be 'the capital of AIDS in South Africa' (Stoch, 2008). There are also rumours of U having an effect on learners in a small village around Carletonville (Tempelhoff 2007; Stoch ,2008,) of which this is in agreement with the concept of U having neurotoxic effects, although the extent to which this can affect human behaviour is still unclear .

In a study on the DNA repair deficiency it was discovered that U can induce DNA repair deficiency in somatic cells Au et al., (1996). In this study non-smoking and non-employee residents of mining and milling sites in Texas, were observed to have higher frequencies of aberrant cells and elevated frequencies of chromosome deletions. Many guidelines and calculation for the effects of U activity only consider its radioactive effects, and the decay products excluding its chemical toxicity. While U may induce radiological effects in organs, nephrotoxic effects from ingested U are more likely due to its chemical as opposed to its radiological properties (Kitto et al., 2005).

2.5 Mining Economic Benefits *versus* Sustainability

The minerals in South Africa are highly diversified, plentiful and profitable thus; government has allowed the industry to be privileged and enabling it to maximize profits at the expense of the environment and consequently human health (Adler et al., 2007). The negative impacts associated with mining are delayed and accumulate decades after mine closure thus the social costs of mining are difficult to predict and regulate. There is a growing realization that mining activities can be undertaken in a fashion whereby economic contributions are maximized, social conditions are improved and damages to the environment minimized. Availability of adequate safe water has been noted to be strongly connected with sustainable development (Massoud et al., 2010).

The primary management issues for underground gold mine closure therefore include long term decant risk, acid mine drainage, water pumping and treatment and the allocation of responsibility especially in the light of the interconnectedness of the mines (Pulles et al., 2005). To ensure public health protection and if sustainability can be achieved; a comprehensive drinking water system has to be set up which integrates water supply, quality and management.

The following section comprehensively lays in brief detail, the current state of the water institution in South Africa and other related statues and policy frameworks so that when an analysis of the effectiveness of these institutions (Section 5.3) with reference to the WFS catchment is made,a baseline has already been created.

2.5.1. South African Legislation (Water Management Institution)

South Africa, according to the 1994 constitution, has a mandate towards achieving and maintaining sustainable development. Thus, the government has had to establish a clear institutional and regulatory framework with quantitative objectives and standards for decision making in terms of mining, environmental and public health protection. The development of laws on water allocation, use and management came with the 1996 constitution having cited the inequities in the ownership and thus the utilization for development, because of the pre-1996 legal framework. The basis of the South African law is thus embedded in the Constitution Bill of Rights Section 27 (1) paragraph (b) which states "the right of every individual to access sufficient water". For the purpose of this section of the research, there is a review of the following policy material with regard to assessment of the institutional set up for water resources management:

- The Constitution of 1996 Act (No.108 of 1996)
- The National Water act (No. 36 of 1998)
- The National Water Resources Strategy 2004
- National Environmental Management (NEM)Waste Act (No.59 of 2008)
- White paper on Integrated Pollution and Waste management 2000
- White paper on Minerals and mining policy

2.5.2 Theoretical context of the:

National Water Act 1998 (NWA)

It was set out to rectify the uneven distribution of water and scarcity. Water is unavailable to the Black South Africans; they have no pipes and taps in many black settlements and squatter camps (Hamann and O'Riordan 2000). Under this law, the riparian ownership of water is converted to common ownership, whereby water is a national resource, owned by the people of South Africa, and held in custodianship by the state. NWA takes cognisance of the aim of water resource management, protection of the water quality and the need to involve all stakeholders, all other aspects of water resources and administration of the law. Other guiding principles to ensure sustainability and equity are used, development, conservation and the control of water resources. NWA has 28 principles some of which include the concepts of user and polluter pays, licensing of water and the registration of water users. The NWA also makes a provision for the creation of a National Water Resources Strategy (NWRS) which is supposed to forge framework guiding protection, conservation, use and management of water resources.

A stipulation in the act (Section 19) places responsibility on persons owning ,controlling ,using or occupying land who has caused or is likely to cause pollution of water to prevent pollution from occurring , continuing or recurring. Section 26 of the NWA also prescribes for the Government Notice No704 (GN 704), which states regulations on use of water for mining and related activities aimed at the protection of water resources.

National Water Resources Strategy (NWRS) 2004

The NWRS is an implementation initiative that outlines the ways and plans of action intended to achieve the integrated management of water resources, whereby there is devolution of powers from national levels to local government. The NWRS has its basis in the NWA as well as the Water Services Act of 1997. This strategy is used to achieve sustainable development. To achieve this, there is a provision which emphasizes the need for the establishment of Catchment Management Agencies (CMAs). The CMAs are expected to draw a water resources strategy which should align itself with NWRS. The CMAs are meant to bring about devolution of responsibilities through a bottom-up participatory approach that delegates control at the lowest levels (the CMAs) and makes use of stakeholder participation. The stakeholders are water users who have to be involved in the decision making process in order to achieve the goals set for water resources management by CMAs.

The content comprises an introductory chapter on water policy, water law and water resources management, and South Africa's water situation and strategies to balance supply and demand. Contained within the strategy are action plans from Policy Implementation Task Teams (PITTs), which were created to identify and overcome constraints from the policy implementation (De Coning, 2006). The NWRS maintains the main aim of the water institution *i.e.* to shift from supply to demand management by enforcing that substantial improvements in water use efficiency are possible if water conservation measures are adopted.

Integrated Water Resource Management (IWRM)

Also incorporated within the NWA is the Integrated Water Resources Management (IWRM) which is described as a "philosophy, process and management strategy to achieve sustainable use of resources by stakeholders at catchment, regional, national and international levels, while maintaining the characteristics and the integrity of water resources at the catchment scale within agreed limits."

IWRM comprises of all aspects of water resources; quality, quantity and aquatic ecosystem quality. In order to achieve IWRM, there are two measures: the resources-directed measures and the source-directed measures .The resources-directed measures are aimed at protecting the receiving environment whilst the source-directed measures are aimed at controlling the impacts at the source.

Mine Management and Closure

There are many legal statutes in South Africa which deal with mine management and closure. One of the aspects set out in the National Environmental Management Act (NEMA) is the need for mining activities to carry out Environmental Impact Assessments EIAs as well as the establishment of closure plans. In the Mines and Minerals Act (MMA) 50 of 1991, as well as the Mineral and Petroleum Resources development Act (MPRDA) 28 of 2002, environmental management is an issue of priority The MMA gives mining companies an obligation of environmental rehabilitation.

The Mineral and Petroleum Resources Development Act 28 of 2002 MPRDA

The MPRDA makes provision for the mitigation of the biophysical and socio-economic impacts. Incorporated within the MPRDA are prescribed requirements specifically for mine closure .The MPRDA stipulates the carrying out of an Environmental Risk Assessment (ERA) whereby risks and financial provisions for long term management and monitoring programs are laid down. It also stipulates the development of mine closure plan which has to be approved by the Department of Water Affairs and Forestry (DWAF) as well as Department of Minerals and Energy (DME). In preparation of the mine closure plan, emphasis is made to involve stakeholders especially the DWAF, which has to sign off on any closure certificate.

Best Practice Guidelines (BPGs)

The DWAF has recently developed and published Best Practice Guidelines (BPGs). The BPGs define and document best practices for water and waste management focused on attending to all the aspects of mine closure planning process. Thus they provide a logical process that can be applied by both the mines and the DWAF so as to ensure that the mines meet the requirements set for mine closure, and that DWAF is satisfied with the mine closure plans. The BPGs are seen as a planning tool to enable mines to implement mine closure and to better address water related mine closure aspects. In the BPG, listed amongst the primary factors for consideration in the planning for mine closure and post closure, is the sustainable rehabilitation of surface residue deposits which if exposed to oxygen may form AMD .In order to achieve the set objectives, the BPGs bank upon stakeholder and specialists participation, the use of appropriate tools, incorporation of financial costs as well as indicators for efficient mine closure planning.

National Environmental Management: Waste Act NEM (WA) 59 of 2008

The NEM (WA) lays a foundation for sustainable integrated waste management and emphasizes the need for intergovernmental co-ordination and harmonization of policies, legislation and actions relating to the environment. In general, waste management falls within the mandate of environmental management authorities and agencies, while the mining authorities with little or no specific reference to mining waste address mining (Godfrey, 2007).

The NEM (WA) sets out the development of a strategy, the National Waste Management Strategy (NWMS). This is an implementation strategy just like the NWRS.

Summary

This chapter has given a cross sectional perspective of the following concepts; sustainable development; the generation and environmental implications of acid mine drainage, the health effects arising as a result of consumption of contaminated drinking water based on contemporary literature. An assessment is also made of the various government publications as well as policy framework in the water institution. The following chapter details the methods and a technique used in the collection, analysis and presentation of data for this study and also provides rationale for the choice of the techniques used.

CHAPTER 3

3. RESEARCH METHODOLOGIES

3.1 Introduction

This chapter outlines the research approach for the study. It gives a detailed account of the sources and types of data, the methods of collection as well as the various analytical techniques employed in the study. Rationalization is given regarding the use of these techniques and principles underlying their application by way of equations; thus creating a basis for the logic in the preceding chapters.

3.2 Research Design

The design mainly used for this research integrated quantitative, experimental as well as qualitative methods with the former being employed to a lesser extent. This is referred to as a multi strategy research approach (Bryman, 2012). Quantitative techniques are used for quantifying the distribution and describing statistically the association of variables while qualitative techniques explore the opinions and attitudes regarding the issues under research. Thus, integrating these two methods simultaneously cancels out and supplements the weakness of either method. Whereas one of the weaknesses of the quantitative approach is decontextualization of human behaviour, it is actually the strength of qualitative strategy.

According to Bamberger (2000), integrating these two approaches, broadens the analytical and conceptual framework of a study. In this case, the integration resulted in the strengthening of the analysis of social, economic, political and cultural aspects of the research. Furthermore, Schmidt (2005) illustrated that an integrated design could aid environmental and ecological anthropologists in their efforts to overcome lack of public engagement and refusal of linkages between human activities. For this research, quantitative methods were mainly used for questionnaire survey and the results from chemical analyses of water and mud samples. On the contrary, the qualitative method was applicable in the reviewing of the South African water institution, where reference was made to literature from other research projects in the field, as well as community perceptions in view of water resources management.

Research Protocol

In maintaining the principles of ethics, applications were made to seek ethical clearance as well as permission to conduct interviews with the communities and the municipalities and approval was given before conducting of questionnaire survey .The application for ethical clearance was done in fulfillment of a requirement of the Masters dissertation with the North West University.

3.3 Research Tools

3.3.1 Data sources and collection

The main sources of data for this study were through structured questionnaires, personal interviews with key informants, collection and analysis of drinking water and sediment samples from the study area. The manner of collection and purpose of the above mentioned are further elaborated.

Questionnaires and interviews

To identify the drinking water sources for formal and informal settlements in the Wonderfonteinspruit catchment, the first step involved the process of identification of all the formal and informal settlements within the catchment. This was followed by the selection of those settlements that were in close proximity to the river. Identification was done using the information gathered from hydrological maps and municipality publications. The identification of all drinking water sources within these two categories of settlements in the following towns; Kagiso, Khutsong, Bekkersdal and Carletonville was done by way of structured questionnaires administered to residents as well as the municipalities' officials and mining companies as will be explained later on in this Chapter.

The choice to use structured questionnaires was made citing the advantages of simplicity in conducting and analysis of the data. Responses to the questionnaires were coded to ensure that they could be easily captured and analyzed. Although generally the structured questionnaires have a disadvantage of lacking creative and exploratory responses (Gillham, 2000), a lot of development work was done to ensure all the possible responses were included prior to the distribution of the questionnaires. In addition, the fixed format of these questionnaires was helpful in cases of illiterate respondents though interviewer bias was introduced in the process.

A pilot study was carried out to determine the strengths and weaknesses of the initial questionnaire. The pilot questionnaire was administered randomly to students, lecturers and community members in Mafikeng and after finding the discrepancies in the design of the questionnaire, corrections and modifications were then made in relation to the findings. The final questionnaire illustrated in Appendix 1 was then administered in the following way:

1) The Communities - Household Water Quality and Supply Survey

Forty residents in each of the four townships under study were given questionnaires (20 in the formal and 20 in the informal settlements).The subdivision was carried out to investigate the patterns and distribution of variables under study in the two categories: the formal and informal settlements. The research was targeting especially the household heads and women. This was done based on the assumption that women and the household heads are the most aware regarding the issues of water consumption at the household level. It is important to note that the survey was targeted at households; therefore, only one individual per household was interviewed. The sample size thus totaled 160 households. The sampling size was reached after considering the resources constraints. Selection of households was done using the systematic sampling criteria. Every fifth household within a 2km radius from the river was selected. Purposive (judgement) sampling was used in the case of inaccessibility to the households, where the nearest accessible house would be targeted. In addition, where residents of selected houses were unavailable, the next available household would be interviewed. Systematic sampling is useful in eliminating bias and improving the representativity of the sample.

The main purpose of the Household Water Quality and Supply Survey was to identify their drinking water sources, efficiency of water provision in the area as well as morbidity of any disease conditions associated with radionuclide and heavy metal contaminants in drinking water. The other aim was to find out the community perceptions regarding the water supply and quality management issues.

2) Stakeholders - Municipality Water Quality and Water Supply Survey

Three municipal officials in the three municipalities (Merafong, Westonaria and Mogale) were given questionnaires particularly those in the Water and Sanitation Departments and in the Department of Environmental Affairs, depending on the organizational structure of the town. The purpose of the Municipality water quality and water supply survey was to ascertain the water sources, alternatives and the measures in place to ensure provision of safe drinking water to the catchment communities (Appendix 2).

The Municipality questionnaire was divided into two sections namely; water sources and uses where information on water supply, consumption and quality was required. Section on water institution and compliance gathered information on the legal statutes for water, general compliance as well as water management related programs such as Integrated Water Resources Management (IWRM). Although the municipality questionnaire was structured with coded answers, the researcher also prompted the interviewees with more questions for clarity and opinion.

3) Mining authorities - Mining Water Supply and Quality Survey

One mining official from one of the mines located in the catchment was also interviewed to determine measures in place to ensure non-contamination of public water sources (Appendix 3).It should be mentioned that although the intention was to interview, mining officials from various mines in the area, only one mine was forthcoming. The questionnaire generally comprised of questions regarding the type of activities, products and bye products; the environmental impacts on water resources; remediation and rehabilitation programs as well as issues on licensing and community development.

Observation

During interviews, observations were made to note some of the disease conditions associated with radionuclide and heavy metal contamination. For example, skin cancers where interviewees voluntarily showed changes on the skin. Observation was also used during the survey to note the socio economic activities occurring in the catchment especially in the areas around the river. Impromptu informal interviews were conducted, to gain more perspective on the water quality and uses of the WFS River.

Water Institution, Legal Statutes and Articles

The researcher assessed the effectiveness of the institutional set up for water resources by making use of literature dating 1996 when the constitution was effected up to 2011, related to water institutions as well as the government publications related to water management. These included:

- The Republic of South Africa constitution of 1996
- The National Water act (No. 36 of 1998)
- The National Water Resources Strategy 2004
- National Environmental Management (NEM)Waste Act (No.59 of 2008)
- White paper on Integrated Pollution and Waste management 2000
- White paper on Minerals and mining policy

The articles targeted were those dealing with the constitutional reform and related to water institution in South Africa. The information regarding the water laws from literature as well as government acts was intensively studied. Gathering opinion from various articles and using case studies of various countries together with findings from questionnaires and water samples the effectiveness of the water institution was assessed.

3.3.2 Data Collection

Water Samples Collection

The Wonderfonteinspruit is the main river passing through the area. As such the water sampling points were selected taking into consideration that the Lancaster dam is the entry point, and that the exit is Harry's dam and two within the study area the Cooke attenuation dam and the Boskop dam. These points were also acting as reference points for the selection of other sampling points which were off the river, depending on the extensive use of the sources of water for domestic and other different activities.

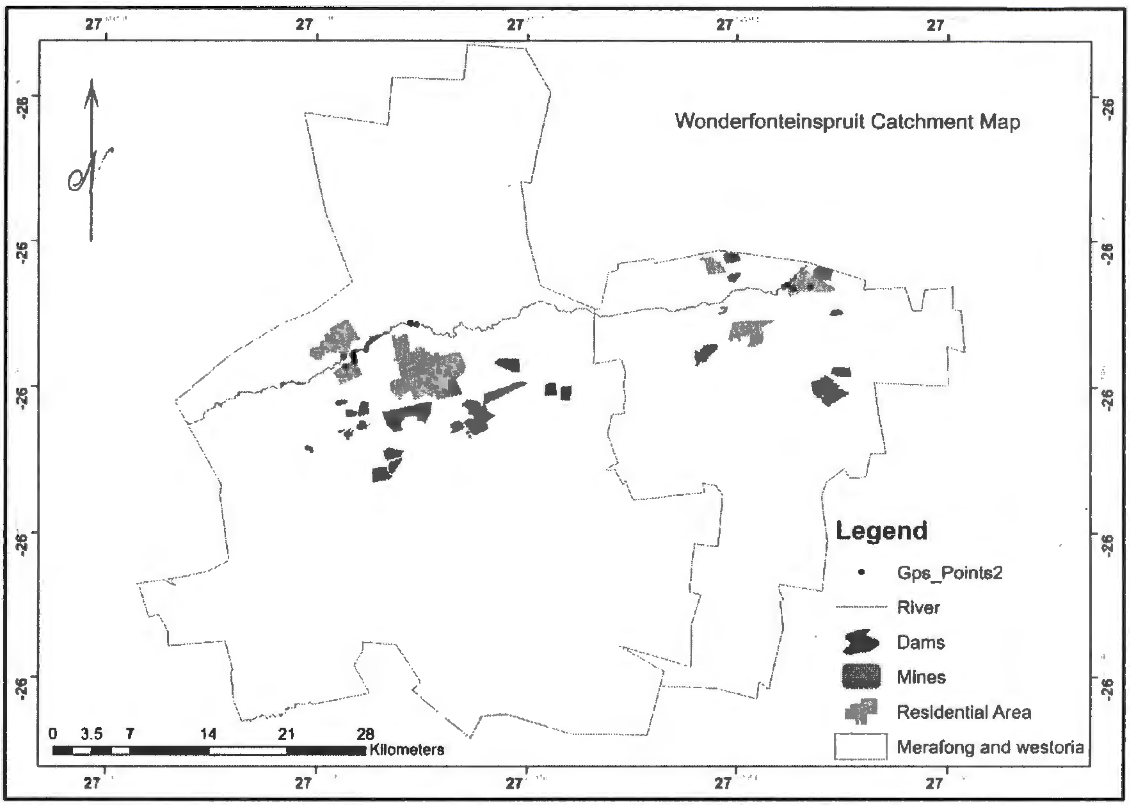

Figure 2: Map of sampling points which were used in the study.

The water samples were collected in the following manner; two sets of water samples, from 12 sampling sites, were each collected during the wet season (summer)March 2012 and in the dry season(spring) in August (2012). For each sampling site samples were collected in triplicates to increase accuracy of findings, thus the samples totaled 72. An additional 7 samples were collected once off for the purposes of microbial analysis. In order to ensure that the sampling points for the beginning of the wet season were the same with the end of the wet season, a GPS was used to record the coordinates for each sampling point as well as to find the exact sampling sites in the other season. Random sampling was used to collect samples in Khutsong, Bekkersdal and Carletonville based on distance of the drinking water sources from the mines and the Wonderfonteinspruit River as well as the type of settlement (formal/informal).

Using 1L HDPE bottles washed in 1% (55% concentrated) HNO_3, water samples were drawn from the different identified water sources. It is also noted that the bottles were rinsed with the sample for three times before any sample was collected. The rinsing of the bottles with the sample was done for acclimatization purposes especially for the microbial cultures. The reason for using HDPE bottles was that they are good at preservation and have a high ability of reducing contamination of the sample. *In situ* measurements for temperature, (hydrogen potential) pH, (Total Dissolved Solids) TDS and electric conductivity (EC) were done using standard procedures (Hemond and Fechner-Levy, 2000) by way of field meters (Mettler Toledo Education Portable EL2-FIELD) ph meter. The information was then captured onto field data sheets. The water samples were pre-treated with 3ml of $HNO_3$for preservation purposes to avoid microbial activity. The water samples were then placed in cooler bags with ice to maintain a temperature of 4°C and immediately transferred to Set Point Laboratories (ISO 17025 accredited) for analysis.

3.3 Data Analysis

The section covers the different methods and techniques that were subjected to the data after collection varying from the statistical techniques, mathematical computations as well as chemical and microbial analytical methods.

3.3.1 Questionnaires

Information from questionnaires and interviews was gathered, captured, transformed and analyzed using Statistical Package for Social Scientists (SPSS) version PASW Predictive Analysis Software version 18.0. Frequency tables were drawn and further cross tabulations were used to describe and estimate the relationships between the concentration of contaminants and variables like distance from the mines and health statistics .Using the questionnaires some indices were devised to evaluate community perceptions as discussed in the following section.

Suitability, Effectiveness, and Disease Awareness Indices

In order to evaluate the community perceptions regarding water quality as well as their confidence in the Municipality water programs and measures, three indices were developed; the suitability index, the effectiveness index and the disease awareness index. The suitability index was developed using four variables from questionnaire responses on; community perceptions regarding the suitability of water for drinking, cooking, bathing and laundry, these were combined into a composite variable termed the suitability index. This was done using SPSS and then a scale ranging from 0 to 4 which constituted the responses, very unsuitable to very suitable respectively, was used. This suitability index was useful in assessing perception on the quality of water for domestic consumption against any other variables.

The effectiveness index was created to determine the perception of communities regarding the measures put in place by the municipality to ensure adequate and potable water supplies. This index was based on two variables sufficiency and efficiency of the municipality measures. Again using SPSS the two variables were combined to form a composite variable which is termed the effectiveness index and based on the responses placed on a scale ranging from 0 to 2 , to describe non effective to very effective, respectively. This effectiveness index was used in the assessment of the municipal programs and initiatives designed to cater for water resources management in the catchment and their efficiency.

The disease awareness index was created based on the responses, aimed at evaluating the knowledge of water quality related diseases. This was based on the number of water quality related diseases known by the respondents; then these were converted into a composite variable. The index ranged from 0 to 7 for no awareness to high awareness respectively, assuming that the higher the number of diseases known, the higher the index. This was used in the analysis of awareness amongst the catchment communities as well as in determining the environmental health education programs existent in the area. As such the analysis was done by cross tabulating this index against other variables like knowledge of water pretreatment techniques, amongst other variables.

3.3.2 Water samples analysis

The water samples were analyzed for heavy metal (Co, Cd, Zn, Pb and As) concentrations as well as U isotopes using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS)

(Appendix 6). This technique employs the use of inductively coupled plasma (ICP) as an ionizing source and the mass spectrometry (MS) is used to determine the elements. ICP-MS method is advantageous in that the use of high temperatures enables the almost complete decomposition of the sample into constituent atoms thus enabling multi element analysis (Ebdon et al., 1998). It also possesses the ability to perform isotope measurements and dilution analysis; especially in this research where there was a need to separate the isotopes. The isotope measurements are a step further in the direction of accuracy and precision. ICPMS has better sensitivity so it can be used for the determination of ultra-low levels of impurities in semi-conductors and long lived radionuclides in the environment (Falciani et al., 2000).

The results from the ICP-MS analysis were checked against the South African water quality guideline values and the World Health Organization (WHO) drinking water standards

3.3.3 Microbial analysis of water samples

Analysis of Water Samples using Conventional Microbiological Techniques

Aliquots of 100 ml of each water sample were filtered through a 0.45μm Grid filter-unit (Type HA) using a Gelman Little Giant Pressure/vacuum pump machine (model 13156-Gelman Sciences, Michigan-USA). The filters were placed on m-FC, mENDO agar plates using sterile forceps to evaluate the level of contamination with fecal and total coliform bacteria respectively. Heterotrophic bacteria in water samples were determined by spread-plating 100μl of sample on plate count agar plates. The plate count agar and mENDO plates were incubated aerobically at 37°C for 24 hours while the m-FC plates were incubated aerobically at 45°C for 24 hours. After incubation, blue and metallic sheen colonies on m-FC and mENDO plates represented fecal and total coliforms, respectively. A colony counter was then used to count these isolates and the results were recorded, as cfu/100ml of water. In general *Staphylococcus aureus*, *Escherichia. Coli* O157:H7, *Enterococcus* species and *Streptococcus* species were isolated from all water samples analysed for both collections. These isolates were identified using species-specific PCR analysis. The indicator bacteria parameters used were total coliform; fecal coliform and the heterotrophic bacterial counts.Total coliforms are Gram-negative bacteria that ferment lactose at35–37°C within 24–48 hrs; fecal thermo-tolerant coliforms are a subset of total coliform bacteria that ferment lactose at 44–45°C and *E. coli* which are exclusively fecal in origin, are a sub-group of the fecal coliforms that produce the enzyme B-galactosidase and not urease (Wright et al., 2004).

3.4 Risk Assessment

To determine the morbidity of any disease conditions associated with uranium isotopes as well as and heavy metal contamination in drinking water, a risk assessment was performed. This is a process of estimating the probability of occurrence of an event and the probable magnitude of adverse health effects over a specified time (Kolluru et al., 1996). In this study, the determination of the risk was twofold: i) the calculations of the radiological annual dose for radionuclides and ii) the risk quotients for heavy metals. The following sections provide details of the assessments.

3.4.1 Radiological annual dose

According to (Chau and Michalec, 2009), the radiological annual dose is the annual dose rate caused by absorption of natural radioactive elements in water, based on the assumption that a man drinks **N** litres per year as stated in the WHO Drinking water guidelines (1998). In other words it is a measure used to interpret the health implications of various radionuclides in drinking water. Therefore, the results create a basis on which epidemiological health surveys can be conducted. Calculations of radiological annual doses for uranium and radium isotopes were done in order to estimate the absorbed radiation from ingestion of contaminated drinking water. The calculations were based on the following equation;

$$D = N \sum n_i \times W_i \qquad (1)$$

Where;

D = radiological annual dose(m/Sv)
N= the amount of water consumed in a year (L)
W_i=the concentration of the given radioisotope (Bq/L)
n_i =Age dependent dose conversion factor (mSv/Bq) for the *i*-th isotope respectively.

The dose conversion factors are defined for specific age groups and take into consideration negative influence of ingested radionuclides for the whole consumer's life (Chau and Michalec, 2009). Calculations of the radiological annual dose have been applied in many studies, especially those dealing with naturally occurring radioactivity in water (Chau and Michalec 2009; Kovacs et al., 2004; Kobya et al., 2010).Since the values that were obtained from the ICPMS for the radioisotopes were in micrograms per liter (µg/L), there was a need to convert these to Becquerels per liter (Bq/L).These units describe the activity of any radioisotope, for which the calculation of D is enabled. This was done by first converting the µg/L to pCi/L (pico curies/liter) and then to Bq/L as is shown below. The computed values of D were finally compared against the WHO drinking water guidelines (2011).

$$A(pCi/L) = C(\mu g/L) * 0.67(pCi/\mu g) \qquad (2)$$

Where A is the radioactivity of the radioisotope, C is the concentration of radioisotope and the conversion factor from (μg/L) to (pCi/L) is 0.67

$$W = A(pCi/L) * 0.037(Bq/pCi) \qquad (3)$$

Where W is the activity in Bq/l and 0.037is the conversion factor from (pCi/L) to (Bq/L).

3.4.2 Risk quotients

A risk quotient is a ratio of exposure and effect. It is useful for assessing whether the contaminant concentrations exceed threshold levels. In the circles of risk characterization and assessment this is termed a tier 1 risk assessment approach. The tier 1 risk quotient approach was found to be valuable for making direct comparisons of quantitative risks in a study on pesticides (Peterson and Hulting 2004). Determination of the risk quotients for all the contaminants under study was done using the following equation:

$$\text{Risk quotient} = \frac{\text{Concentration of contaminant}}{\text{Regulatory limit for contamination}} \qquad (4)$$

Whereby if the risk quotient is less than 1 it means there is no significant health risk but if it is equal to or exceeds 1 it means there is a significant health risk.

Lifetime Cancer Mortality and Morbidity Risk

The lifetime cancer risks, R, either for mortality or morbidity, associated with intake of a given radionuclide were estimated from the product of the applicable risk coefficient *r*(mortality or morbidity) and the *per capita* activity intake I expressed in equation (5).

$$R = r \times I \qquad (5)$$

This equation takes into consideration the activity of the radionuclide in water and the amount of water consumed the product of which is represented by **r** and the life expectancy of the consumers (1).

3.5 Statistical analyses

Statistical analyses are used to describe, explain, understand and prove concepts under investigation. Various statistical techniques were used in this study, in assessing and analyzing the various data that had been collected. These techniques varied from descriptive statistics (means and standard deviations) to inferential statistics (correlation analysis and the independent t test). Each of the various statistical techniques was applied to serve a particular purpose. The following section, describes these statistical analysis methods, how they were used and the rationale behind their use.

Mean and standard deviation was computed for each sampling point since the samples were collected in triplicates per site. The independent t test was used to establish variations of metallic concentrations seasonally and as well as according to settlement types. The formula for the t statistic is as follows;

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - (u_1 - u_2)}{S_{(\bar{x}_1 - \bar{x}_2)}} \quad (6)$$

Correlation can be defined as an analysis of relationships between two or more variables, whereby a systematic change in the value of one value may lead to a systematic change in value of the other. In other words correlation measures the degree of association between two variables. In order to do this analysis, in this study there was use of a correlation coefficient. The formula for which is as shown below. In this study the Pearson's Correlation was used to establish the association between the presence of contaminants in the drinking water and the incidence of contamination related diseases.

$$r_{xy} = \frac{\sum_{i=1}^{n}(x-\bar{x})-(y-\bar{y})}{\sum_{i=1}^{n} \sum_{i=1}^{n}(x-\bar{x})-(y-\bar{y}))} \quad (7)$$

r_{xy}=correlation coefficient of two variables

$\sum X_i, \sum Y_i$= sum of individuals

It was also used in assessing the degree of association between the following variables; the effectiveness index and water quality problems, the effectiveness index and water shortage events and contaminants concentrations for different settlement types

Summary

This chapter has outlined the research approach (the mix method /integrated) and the rationale, for the various techniques employed in the gathering, analysis as well as presentation of findings. Clearly the integration of qualitative and quantitative methods are justified since, the data that is used in the research varies and thus requires different methods of analysis, henceforth combining these two methods ensures that the weaknesses of either methods cancels out the other. The results of findings from various data analysis are presented in Chapter (4).

CHAPTER 4

4. DRINKING WATER QUALITY IN THE WONDERFONTEINSPRUIT CATCHMENT

In this chapter, there is presentation and discussion of findings on the drinking water sources, the drinking water quality and health related risks arising thereof. These findings emanate from the water analysis; (physico-chemical and microbial) as well as some of the findings from the household survey. Presentation of data is in the form of graphs, tables, pie charts and statistical analyses. In the beginning, the focus is on the water sources, the uses of the water as well as various dynamics influencing the access to and type of water sources. This is preceded by a discussion on the *status quo* of water quality from the identified water sources. At the end of this chapter there is a section that looks at correlation between the findings from the survey on water related diseases and water quality results. In conclusion, a brief summary of the significance of the results is given.

4.1. Household Water Quality Survey

The results from the household water supply and quality survey are presented by way of these categories: water sources and uses, water quality and community perceptions and health and awareness.

4.1.1 Water sources and uses

Water supply has a direct impact on the economic development of any country. This is because it has to support food production, manufacturing and various other water dependent societal supplies. The Wonderfonteinspruit catchment (hereafter referred to as WFS) harbours significant thousands of informal settlers who have migrated in pursuit of better economic opportunities like mining, small-scale agriculture and other related job opportunities.

Figure 3 shows that all of the respondents in Khutsong, Kagiso and Bekkersdal and approximately 19 of the respondents in Carletonville respectively indicated tap water as the most common "main" water source.

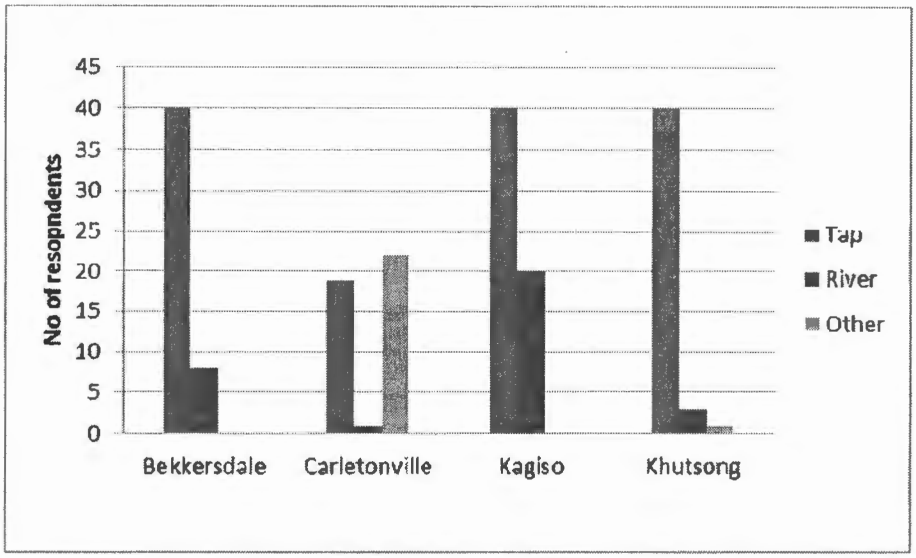

Figure 3: Main water sources in the Wonderfonteinspruit catchment

From observations and informal interviews, there are variations in the types of water sources. For instance, most of the residents in informal communities do not have tap water in their yards except for some sections in Carletonville and Bekkersdal who have Jojo tanks and communal standpipes respectively. This conforms with findings from a Bloemfontein study (South Africa) where a majority of respondents indicated that they had access to tap water and yet none of the respondents in the informal settlements had water delivered to their dwellings (Pretorius and De Villiers, 2002).

Another notable aspect was that about 22 of the respondents in Carletonville and 1 in Khutsong stated that they had 'other' main water sources in which case refers to water from formal settlements (location) which are over at least 1km away. Additionally, 32 of all the respondents stated that the river was their main source of water for domestic consumption ,with the highest proportion of river use coming from Kagiso(20) and Bekkersdal (8).None of the respondents stated that they used borehole water, even though in some settlements people were found using them. However, since municipality officials accompanied the researcher, it was apparent that some people were afraid to admit that they were using borehole water since boreholes were prohibited.

Domestic uses for tap water vary from drinking, cooking, bathing and laundry. The uses for tap water vary across settlements with accessibility (Figure 4). For example, 98.8% of the respondents in the formal settlements use tap water for all their domestic consumption purposes including drinking, cooking, bathing and laundry as compared to 71.3% in the informal settlements.

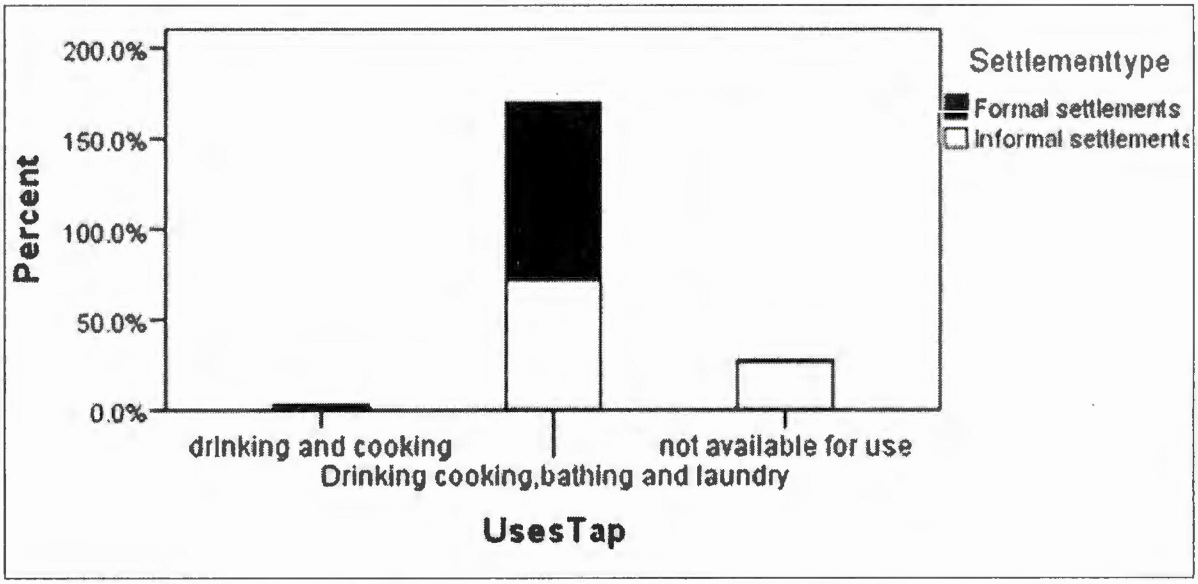

Figure 4: Distribution of domestic uses of tap water in WFS catchment by settlement type

The study revealed that 26.3% of the respondents from informal settlements do not have tap water available to them for use or they have inadequate supplies (1.7%).As such, tap water is only used for drinking and cooking. This may be due to the formal settlements having access to tap water compared to the socio-economically disadvantaged informal settlements that have to manage the little they have and augment with alternatives.

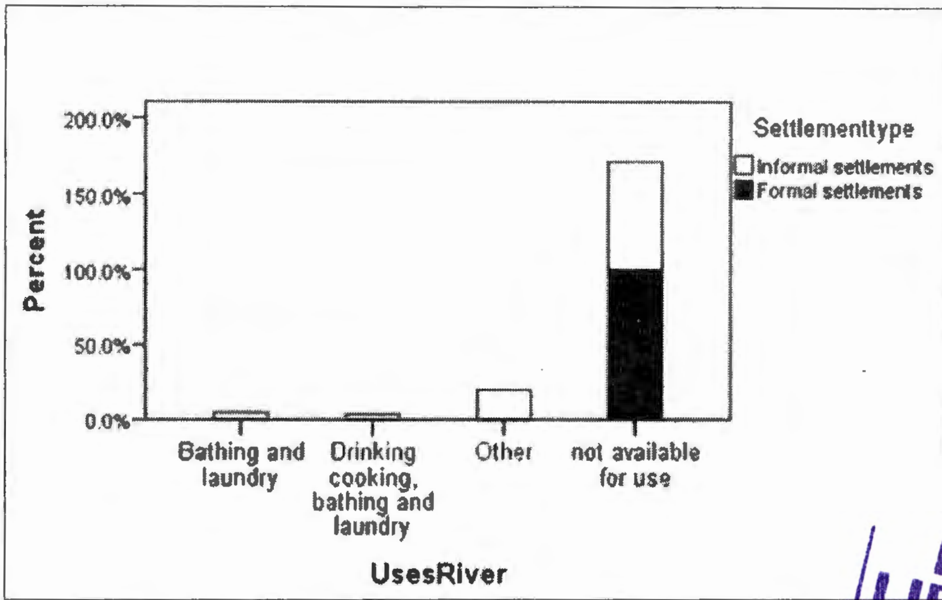

Figure 5: Domestic uses for river water in the WFS catchment by settlement type

The distribution of respondents based on the use of the WFS River as their source of water as shown in Figure 5 indicates that 20% of the informal settlers use river water for other purposes (ritual, watering livestock and gardens). Results indicated that 4% of the respondents use river water as their main source of domestic water supply while 5% uses it for bathing and laundry only.The use of river water for bathing and laundry purposes only possibly constitutes the 2% in informal settlements who have access to tap water but use it only for drinking and cooking. However, a small proportion of the respondents access tap water but at some distance.

The highest occurrence of water shortages is in informal settlements that recorded 72% response as compared to 28% in formal settlements as illustrated in Figure 4. This is attributed to the lack of tap water and communal water points in the informal settlements (Kagiso and Khutsong). In addition, the contribution of water shortage in Carletonville emanates from the municipalities' delays in filling the Jojo tanks. It is also important to note that during the time of the survey, the Merafong municipality was having a crisis in Khutsong formal settlement, whereby residents had gone without water for weeks and water had to be delivered by water trucks. Formal settlements experience water shortages but the severity is less relative to informal settlements. Table 3 shows the variations in water shortage and type of settlement.

Table 3: Cross tabulation of existence of water shortages with type relative to settlement types

			Settlement type		Total
			Informal	Formal	
Water shortages	Yes	Count	59	23	82
		% of total population	72.0	28.0	100.0
		% by Settlement type	73.8	28.8	51.3
		% of Total	36.9	14.4	51.3
	No	Count	21	57	78
		% of total population	26.9	73.1	100
		% by Settlement type	26.3	71.3	48.8
		% of Total	13.1	35.6	48.8
Total		Count	80	80	160
		% of total population	50.0	50.0	100
		% by Settlement type	100	100.0	100
		% of Total	50.0	50.0	100

Occurrence of water shortages recorded a 72% response in informal settlements compared to 28% in formal settlements. During the water shortages, communities augment their water with a number of alternatives as illustrated in Figure 6.

Findings revealed that 50.63% of the respondents do not have alternative water sources. In contrast, the most common alternative is the river, with 16.5% use, while 7.5% supplement water shortages with both river water and bottled water. Another proportion of the respondents, about 21% indicated that they draw water from nearby schools or buy from mobile trucks. A small proportion indicated that they use bottled mineral water that is deemed more of luxury than a necessity.

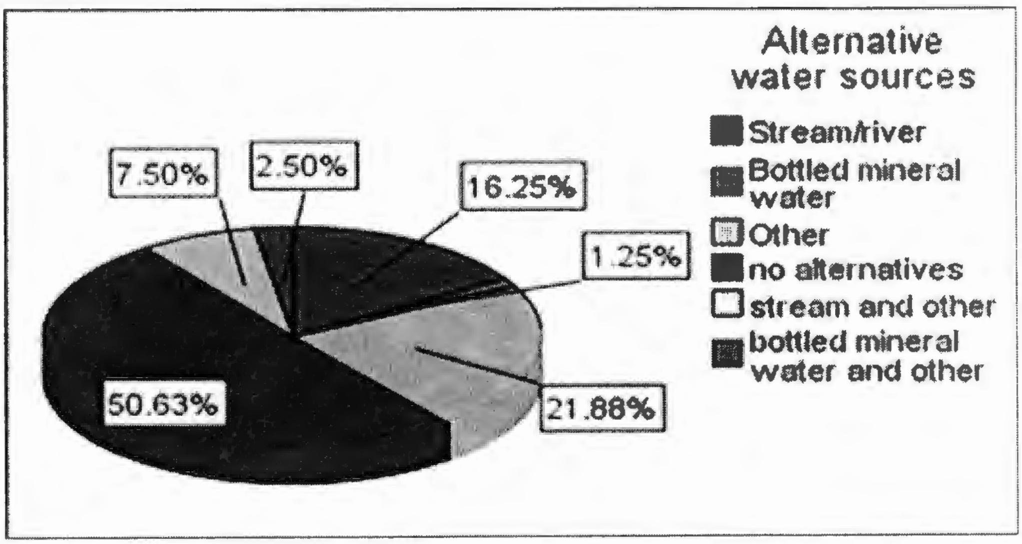

Figure 6: Alternative water sources in the Wonderfonteinspruit Catchment

Except for river water, all the other alternatives require some payment. Most of the people who use these alternatives are coming from informal settlements. Table 4 shows the distribution of variations in alternative water sources.

Table 4: Settlement type and alternative water sources cross tabulation

Settlement type	Alternative water sources					
	Stream/River	Mineral water	None	Other	Stream & Other	Mineral water &Other
Informal	16.25%	1.3%	9.4%	15.6	7.5%	0%
Formal	.0%	.0%	12.5	35.0	.0%	2.5%
Total	16.3%	1.3%	21.9	50.6	7.5	2.5

Findings indicate that alternatives vary with type of settlement whereby all of the people who use the river as their alternative are from informal settlements (23.8%). This is in actual fact evidence of failure by municipal authorities to acknowledge the reality of informal settlements, and the need for services that comes along with their existence .Thus there is a tendency by municipalities to neglect most of these informal settlements since their dwellings are considered illegal, consequently they lack piped water systems. Moreover, the informal residents cannot afford paying for municipal services and have been labeled as lacking willingness to pay for these services.

As shown in Table 4, the majority of residents with no alternatives are formal residents (12.5 %) because the water shortages are seldom, short-lived and less severe. They frequently wait for water to be re-pumped in instances of water shortages. The other alternatives vary from, buying from trucks, schools and formal settlements, to waiting for the water to be re-pumped. It is worthwhile to mention that mineral water is the least used alternative in both the informal and formal settlements because it is viewed as a luxury. This shows the misconception in developing countries amongst people that mineral water is safe and yet in the developed world, bottled mineral water has been shown to contain radioactivity (Chau and Michalec, 2009).

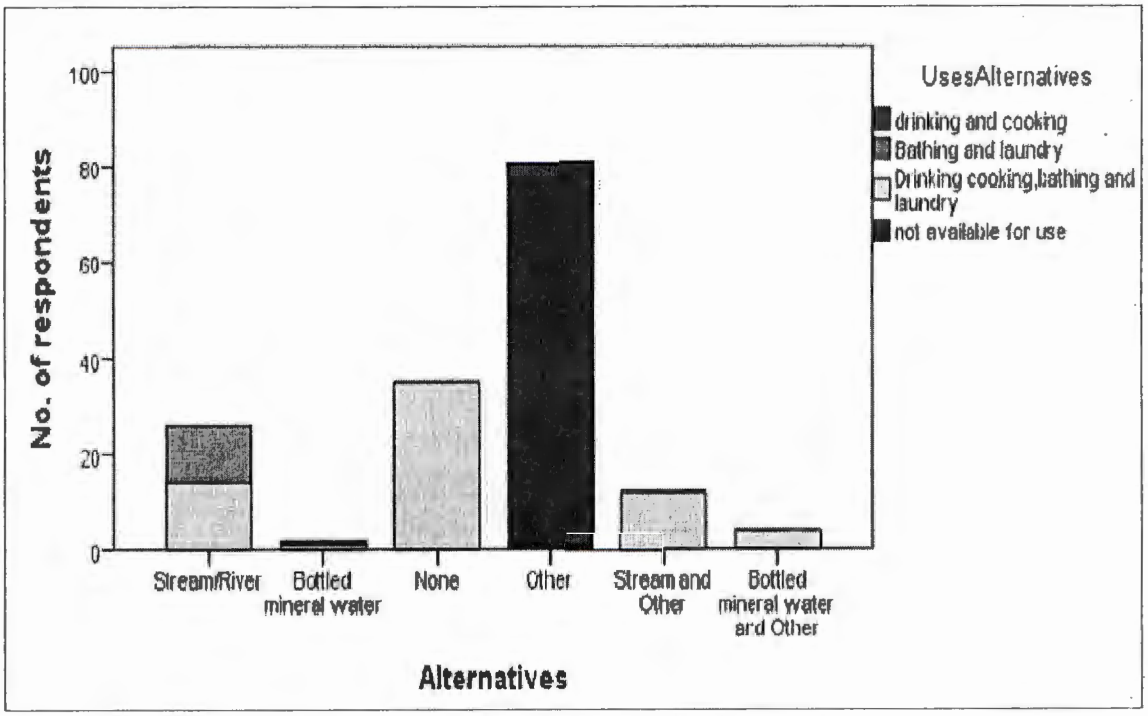

Figure 7: Different domestic uses for alternative water sources

Figure 7 shows the different uses of these alternatives, which vary from drinking, cooking, bathing and laundry by 16.3% of the respondents to selected uses (bathing and laundry only) 7.5%. Bottled mineral water is used for drinking and cooking only (0.6%) and supplementing with other sources whilst 2.5% use bottled water for all domestic purposes.

In order to assess the economic characteristics of respondents, questions were asked regarding the respondents' occupation. The assessment was however not based on how much they get from their occupation but on the assumption that some sort of activity brings income to the household and enables them to afford potable water. It should be mentioned that the employment category (especially in the informal settlement) is not "white collar" job but rather unskilled and semi-skilled employment which include such activities as labourers in the mines, vendors and hawkers. It was noted that livelihood strategy to some extent also determines the alternative water sources.

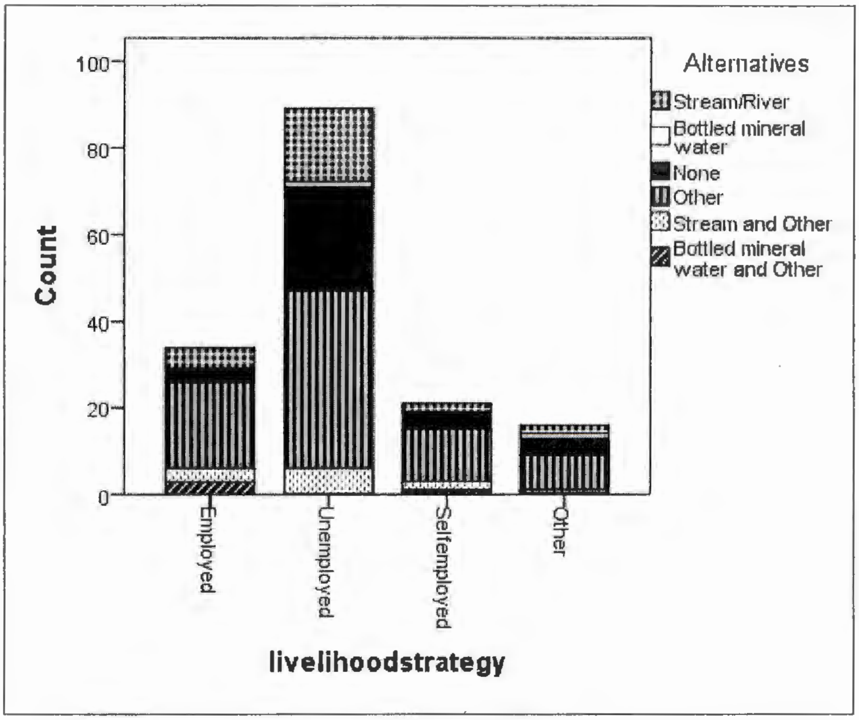

Figure 8: Alternative water sources by livelihood strategy

The results indicated that the highest proportion of river use (10.6%) constituted unemployed residents (Figure 8). Similarly, those who had no alternatives constituted 15% who responded to being unemployed. This could be accounted for by the inability to pay for the expensive alternatives by these unemployed residents.

The alternatives were cross tabulated with frequency of water shortages to illustrate the frequency of use for each particular alternative. Figure 9 shows that 4.4% of residents who experience water shortages on a daily basis tend to use the stream as their alternative. It is also interesting to note that some residents who stated that they never experience water shortages still use the river as their alternative. Other trends from the findings depict that some proportions (3.1%) of people who use bottled mineral water as an alternative, only experience water shortages on a yearly basis. In contrast, 3.1% of those who do not have alternatives, experience water shortages on a daily basis.

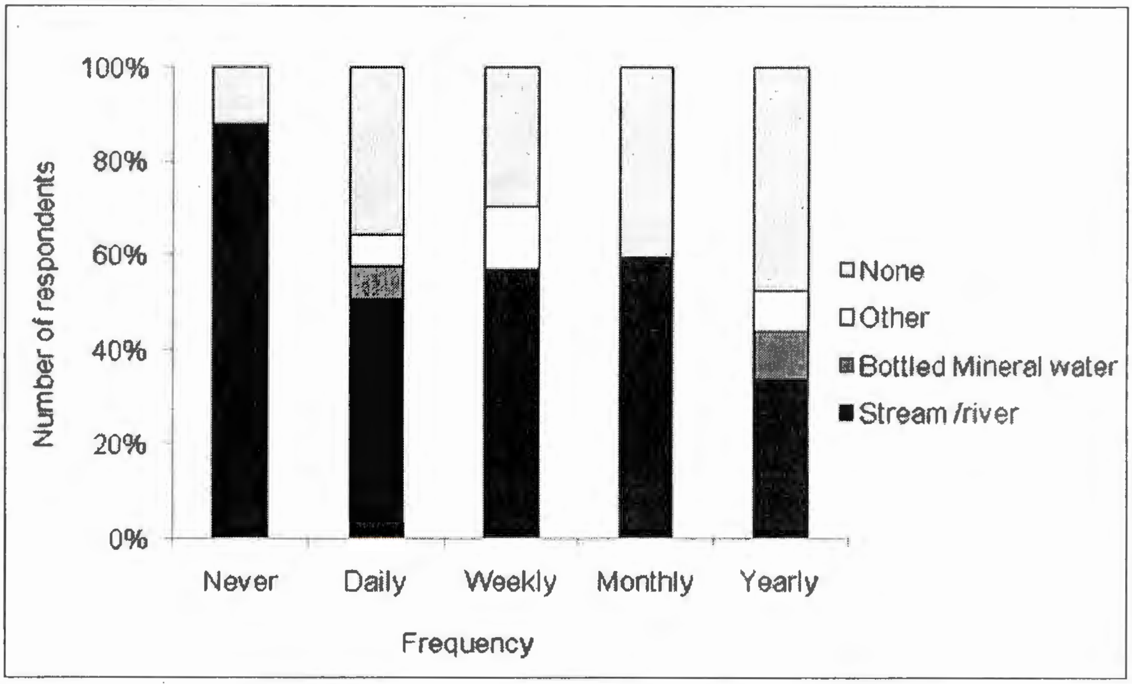

Figure 9: Frequency of use for alternatives

4.2. Water Quality and Health Implications

In the following section results on water quality are presented and these include; the physicochemical, microbial, heavy metals and radionuclides concentrations respectively. These results are compared against the SANS 241, 2011 and WHO 2011 standards, and using literature from related studies, the significance of these results on health of the consumers is discussed.

4.2.1 Microbial Quality of the Drinking Water

Three types of indicator organisms reported here include fecal coliforms, total coliforms and the heterotrophic plate counts (Figure 8). Results of microbial analysis revealed that there is high microbial activity in all the water samples and this is substantial evidence of fecal contamination and pollution in general. WHO (2011), stipulated that *E.coli* and thermotolerant coliform bacteria must not be present in any 100ml sample of drinking water. All samples except for the Carletonville Jojo tank were above zero which is the maximum permissible for fecal, total and heterotrophic coliform count in drinking water. The highest fecal coliform count was recorded in the Khutsong informal settlement along the river. For the total and heterotrophic coliform categories of bacterial indicators, counts followed this order Bekkersdal>Khutsong>Carletonville.

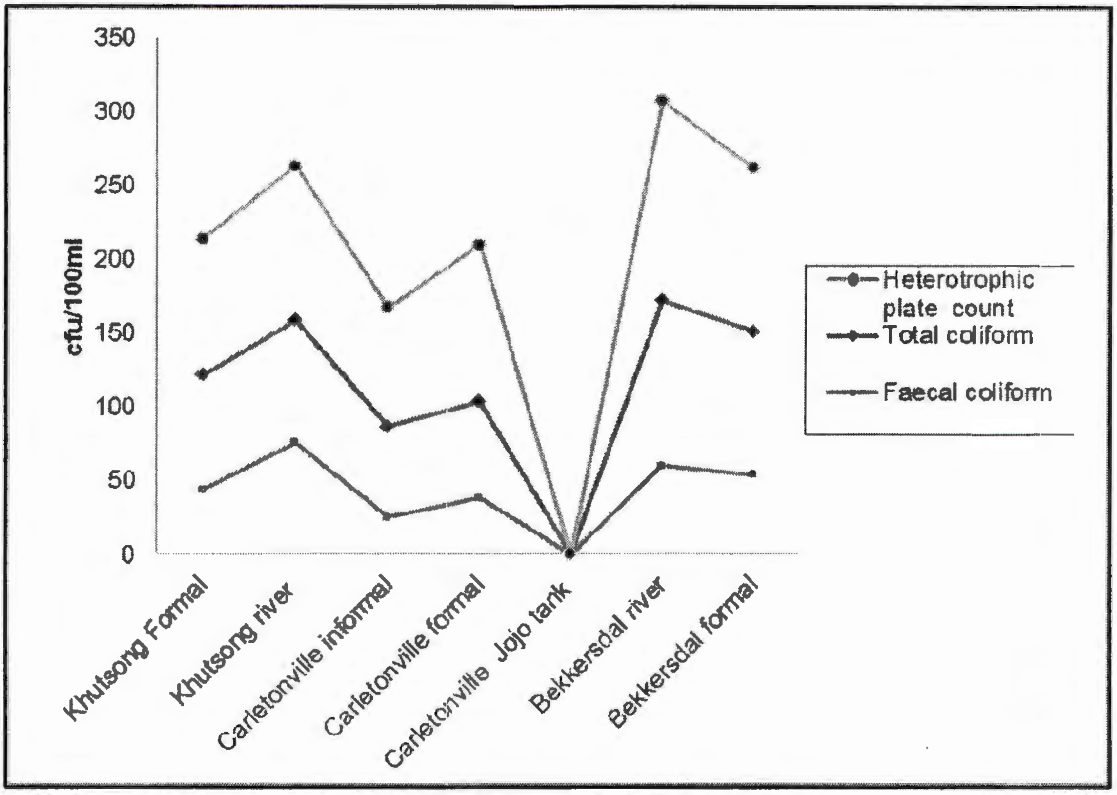

Figure 10: Microbial quality of drinking water

Interestingly high counts of total coliform bacteria were noted in treated water samples from Khutsong and Bekkersdal (Figure 10). The presence of fecal and total coliforms in the treated water may be an indication of inadequate treatment of water. Similarly, there were high numbers of total and fecal coliforms in water recorded in a study in Egypt (Karem and Hassam, 2000),this was attributed to lack of cleaning of the storage tanks which is also the opinion shared by the people in the Carletonville area who have Jojo tanks. On the contrary, a study on assessment of quality of water from source to storage, it was revealed that the decline in water quality in terms of fecal and total coliforms is proportionately greater, where source water is largely uncontaminated relative to the stored water (Wright et al., 2004). The Jojo tanks in this case recorded no microbial contamination. The high microbial activity in the river suggests possible contamination from human activities that vary from bathing, laundry, recreational to livestock production, since there are some small scale farmers residing along the river. It is also a common practice for people residing next to the river to discharge their waste in the rivers (Karikari and Ansa-Asare 2006).

According to Kirschner et al., (2009) water containing total or fecal coliforms above the drinking water guidelines should not be used for drinking or food preparation without disinfection because coliforms indicate the presence of fecal matter in the water. The consumption of this water can lead to stomach and intestinal illness including diarrhea and nausea (Ajeagah et al., 2011).Fecal matter carries all diseases existent in a particular population (WHO, 2004), thus if the contaminated water is not properly treated, one sick person's wastes can spread the disease epidemically (WHO and UNICEF, 2004).

4.2.2 Physicochemical Quality of Drinking Water

In order to better understand the chemical processes, and the mobility of contaminants in the water sources in the WFS catchment; it is very important to understand the physicochemical parameters, of the water. The parameters that were used under this category included temperature, pH, electrical conductivity (EC), sulphate and total dissolved solids (TDS).

Temperature

The temperature of water from the drinking water sources ranged from 17.7°C to 18°C during both seasons. Acceptable drinking water temperature is stipulated to be 18°C thus all the water sources were within the acceptable temperature limit. Cool water is generally more palatable than warm water, and temperature will have an impact on the acceptability of a number of other inorganic constituents and chemical contaminants that may affect taste (WHO, 2011).

pH

The acceptable levels for pH in drinking water are stipulated to range from 6.5 to 8.5, which also conforms with the findings that unpolluted waters exhibit pH values in the range of 6 to 9 (Davis 1992). Any pH value below 7 is considered to be acidic and above 7 is considered to be alkaline. Based on this, all the identified drinking water sources were out of this acceptable range. Table 5 shows results of the pH obtained from the drinking water sources.The pH range for the water samples was mainly very acidic ranging between 1.4 and 1.8, which is characteristic of acid waters, with relatively low H^+ species diversity (since pH is a measure of the hydrogen ions H^+) and low productivity (Davis 1992).

Table 5: Mean and standard deviation values for hydrogen potential (pH)

	pH	
	Wet season	Dry season
Khutsong informal pt 1	4.82±0	4.20±0.06
Khutsong informal pt 2	4.75±0.1	4.07±0.06
Khutsong formal pt1	6.89±0.12	6.9±0.06
Carletonville informal pt 1	5.29±0.053	4.89±0
Carletonville informal pt 2	5.35±0.1	4.52±0.15
Carletonville Jojo tank 1	6.38±0.06	6.50±0.06
Carletonville Jojo tank 2	5.49±0.05	6.4±0
Carletonville formal pt 1	6.18±0.37	6.54±0.1
Bekkersdal informal pt 1	5.15±0.06	3.971.5±0
Bekkersdal informal pt 2	5.65±0.06	3.84±0.1
Bekkersdal standpipe 1	6.20±0.12	6.87±0.06
Bekkersdal formal	6.58±0.05	6.53±0.06
Guidelines		
SANS 241	$\geq 5 - \leq 9.7$	
WHO	Not prescribed	

The pH of acid mine drainage waters is largely controlled by the rates of pyrite oxidation, presence of acid neutralizing minerals and dilution by mixing with other water sources (Akcil 2006). Of great significance is the low pH which was recorded for tap water samples taken in the formal settlements, these low pH values in treated piped water may lead to corrosion of the pipelines thus the consumption of metal contaminated water. The low pH recorded in the tap water could be attributed to the old distribution system and poor treatment. The pH is important because it determines the chemical reactions that take place for example the co-precipitation of heavy metals. Metal concentrations tend to increase when pH decreases. Further discussion on pH is in Section 4.2.3 of this thesis.

Electrical Conductivity

The electrical conductivity (EC) is a measure of the total amount of the dissolved ions/salts in the water. It can be used to infer the level of concentrated heavy metals in water but it does not give an indication of which element is present.Generally, EC was high in the range of 1300-1850 mS/m for the wet season and relatively lower during the dry season, between 1196- 1473 mS/m which in both seasons is in excess of the SANS 241 and WHO limit pegged at >150 mS/m and this is for aesthetic purposes (Table 6).

Table 6: Mean and standard deviation values for electrical conductivity

	Electrical conductivity	
	Wet season	Dry season
Khutsong informal pt 1	1308±39	1222±149
Khutsong informal pt 2	1522.3±237	1196.3±41
Khutsong formal pt1	1559.3±442	1276±128
Carletonville informal pt 1	1830±689	1415±134
Carletonville informal pt 2	1176.3±170	1302±316
Carletonville Jojo tank 1	1271.3±220	1397.3±29
Carletonville Jojo tank 2	1418±27	1382.7±93
Carletonville formal pt 1	1367±37	1263±285
Bekkersdal informal pt 1	1675.3±443	1361.3±40
Bekkersdal informal pt 2	1405±145	1473.7±254
Bekkersdal standpipe 1	1508±144	1422.3±115.
Bekkersdal formal	1448±83	1432±171
Guidelines (mS/m)		
SANS 241		≤ 170
WHO		≤150

For both seasons, the highest EC was recorded along the river in Bekkersdal and the least in Carletonville for the dry season and Khutsong for the wet season. For the formal water sources, the highest recorded EC was for tap water in Khutsong. The very high values of EC along the river could be indicative of the discharge of polluted mine waste water into the river. In this case, the high EC cannot be tallied with metal concentrations which were mostly low especially during the dry season (Section 4.2.3 of the thesis).

Nonetheless, higher values of EC are a good indicator of the presence of contaminants such as sodium, potassium, chloride or sulphate (Orebiyi et al., 2010). Along with sulphates, EC has been labeled one of the most reliable indicators of mining effluents than pH and heavy metals (Gray 1996). Health problems are known to occur when the EC exceeds 370 mS/m, leading to blood pressure problems and the disturbance of water and salt balance in children (DWAF 2001).

Sulphates

The distribution of sulphates, which also have a control on the EC of water, followed a similar trend to that of the EC. Due to the low pH values, the sulphate concentrations and the EC were high though the sulphates were relatively lower compared to the EC (Table 7).

Table 7: Mean and standard deviation values for Sulphates

	Sulphates	
	Wet season	Dry season
Khutsong informal pt 1	188.3±1.5	**213±5**
Khutsong informal pt 2	187.7±1.5	**223±13**
Khutsong formal pt1	10±2	11.7±0.6
Carletonville informal pt 1	**264±49.4**	230±11.3
Carletonville informal pt 2	199±1	**223.7±15.3**
Carletonville Jojo tank 1	9.3±3.2	11.7±1.2
Carletonville Jojo tank 2	6.3±0.6	10.3±0.6
Carletonville formal pt 1	8±1	10.7±0.6
Bekkersdal informal pt 1	96.6±82.2	**289.3±57.5**
Bekkersdal informal pt 2	113.0±2	**253.3±0.6**
Bekkersdal standpipe 1	8.7±2.1	8.8±6.4
Bekkersdal formal	7.3±0.1	12.3±0.6
Guidelines (mg/L)		
SANS 241		500
WHO		200

Noticeable are variations between the dry and wet season concentrations of sulphates in the water with high concentrations during the dry season. During the wet season, the highest sulphate concentration was recorded in Carletonville along the river (264 mg/L) while during the dry season; the highest was 289 mg/L. The concentrations were within the acceptable limits of both SANS 241 and WHO (2011) where levels are not to exceed 500 mg/l and 200 mg/l respectively. Although WHO has derived no health-based guideline value for sulphate, it is generally considered that taste impairment is minimal at levels below 250 mg/L (WHO, 2011). For the formal water sources during both seasons, the sulphate concentrations were very low and in line with the standards, whereby the maximum was recorded at 12 mg/L. The synergistic effect of high sulphates and EC along the river may potentially manifest laxative effects to those who consume the water (German et al., 2008) especially since in this study there were points along the river which exceeded the stipulated 250ml, coupled with the high EC,it could lead to an outbreak.

Total Dissolved Solids

According to WHO (2011), there is no health based limit for TDS in drinking water. The analysis results of the samples indicated that the water had very high values of TDS with the lowest being 5881.5mg/L and the highest 8376.5mg/L ,both recorded during the wet season(Table 8).The TDS was high for all the sampling points in the informal and formal settlements. The high values of TDS were also consistent with the high EC recorded in all the water samples during both seasons.

Table 8: Mean and standard deviation values for total dissolved solids

	Total dissolved Solids	
	Wet season	Dry season
Khutsong informal pt 1	6540±2	6110±2.31
Khutsong informal pt 2	7611.5±8.72	5980±2
Khutsong formal pt1	7796.5±0	6380±0
Carletonville informal pt 1	9150±1.16	7075±1.2
Carletonville informal pt 2	5881.5±2	**6510**±3.1
Carletonville Jojo tank 1	6356.5±0	**6986.5**±0
Carletonville Jojo tank 2	7090±0	6913.5±1.15
Carletonville formal pt 1	6835±0	6315±0
Bekkersdal informal pt 1	8376.5±2.70	6806.5±3.5
Bekkersdal informal pt 2	7025±0	7368.5±11.0
Bekkersdal standpipe 1	7540±0	7111.5±0
Bekkersdal formal	7240±0	7166±0
Guidelines (mg/L)		
SANS 241		≤1200
WHO		1000

TDS occurs in drinking water at concentrations well below toxic effects, but the palatability of water with TDS levels of less than 600 mg/L is generally considered good (Bruno et al.,2008). Drinking water becomes significantly and increasingly unpalatable at TDS levels greater than about 1000 mg/L (Bruno et al., 2008).TDS values greater than 1200 mg/L may be objectionable to consumers and could have impacts for those who need to limit daily salt intake e.g. severely hypertensive, diabetic, and renal dialysis patients (London et al., 2005).

4.2.3 Chemical Water Quality

Heavy metals

Findings from water analysis generally reveal that the various metallic concentrations at the sampling points were not spread about the mean since the standard deviation values were not close to zero in most cases. Generally, the heavy metals high concentrations followed this trend Zn>Co>As>Pb>Cd. The metal with the highest concentration recorded was Zn with a maximum of 172 µg/l and the metal with the least concentration was Cd with a maximum of<0.1 µg/l when comparing the concentrations against the SANS 241 (2011) and WHO (2011), the only metals which were in excess are As and U. The presence of these two elements in drinking water might result in the occurrence of skin lesions and kidney problems. The following sections provide detailed explanation of the concentrations and health risks associated with heavy metals.

Arsenic

Arsenic concentrations in water are determined by various complex, geochemical, chemical and biochemical reactions. Its solubility is largely dependent on the pH where it becomes more soluble with an increase in pH. As tends not to migrate over long distances thus its distribution in water tends to be localized around the source of pollution. This is attributed to the strong affinity of oxide minerals for As under mildly neutral to acidic conditions. Table 9 shows results of As concentrations from the study area at the various sampling points during the wet and dry seasons.

Table 9: Mean and standard deviation values for arsenic

	Arsenic(µg/L)	
	Wet season	Dry season
Khutsong informal pt 1	8.2±0.13	**10.8±1.2**
Khutsong informal pt 2	7.9±0.06	**12±3.4**
Khutsong formal pt1	0.7 ±0.09	0.5±0
Carletonville informal pt 1	**14.2±0.06**	**16.2±0.55**
Carletonville informal pt 2	**14.9±0.2**	**14.3±0.15**
Carletonville Jojo tank 1	0.5±0.04	0.5±0
Carletonville Jojo tank 2	0.6±0.01	0.5±0
Carletonville formal pt 1	0.6±0.01	0.49±0.001
Bekkersdal informal pt 1	**11.6±0.4**	9.6±0.4
Bekkersdal informal pt 2	**12±0.2**	4.3±0.4
Bekkersdal standpipe 1	0.65±0.03	0.5±0
Bekkersdal formal	0.7±0.01	0.5±0
Guidelines (µg/L)		
SANS 241	10	
WHO	10	

The concentrations of As were high along the river compared to the formal water sources for both the dry and wet seasons recording 16.17 µg/L and 14.93 µg/L respectively, compared to the formal water sources which had a maximum of 0.67 µg/L (wet) and 0.49 µg/L (dry). Several points along the river were observed to be exceeding WHO and SANS (241) 2011 standards in Carletonville, Khutsong and Bekkersdal. Noticeable were the relatively higher As concentrations for the formal water sources during the wet season compared to the dry season. However, the trend was completely opposite for informal water sources where As concentrations were higher during the dry season and this can be attributed to high rates of evaporation characteristic of the dry season, in the absence of saturation species resulting in an increase in solutes and hence high EC and low pH (Tutu et al., 2008), these variables control the precipitation and adsorption of metals like As in solution.

An independent t test to determine the equality of mean As concentrations between seasons at 95% confidence interval (t=0.934) (Appendix 6 Table 28) revealed no statistically significant difference between the As concentrations in the dry and wet season. Correspondingly, in a study on the temporal and spatial variations of As in Michigan using descriptive statistics, it was concluded that there were no seasonal variability in mean As concentrations (Slotnick 2002).The high concentrations of As could be attributed to acidic mine waters and significant increase in Fe and As (Nordstrom et al., 2000).In this study, the acidic conditions along the river might have led to the rapid removal of dissolved As whilst iron was oxidised and precipitated (Nordstrom et al., 2000).The wet season was characterized by many irregular stormy events in the WFS, leading to the contribution of solutes from the soils and thus a high EC. These stormy events are liable for the sudden increase in solute chemistry, leading to weathering products being exposed to runoff (Sultan and Dowling, 2005), as is indicated by the levels of As in water during the period.

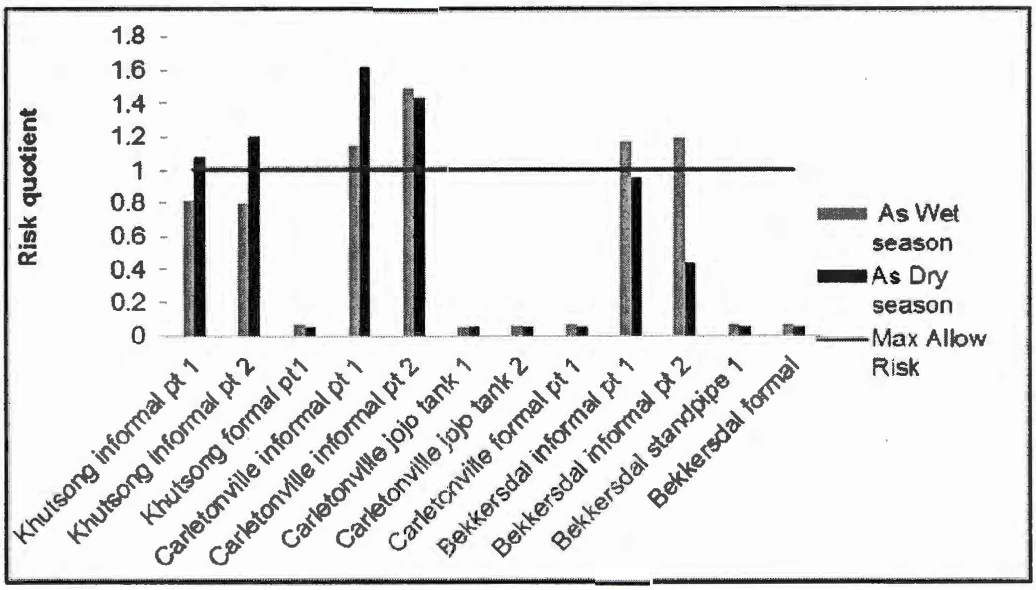

Figure 11: Arsenic risk quotient in the WFS

To determine the risk emanating from the recorded As concentrations in drinking water, a risk quotient was calculated against the maximum allowable risk of 1 (Figure 11). The trend depicts association between high concentrations in excess of the standards and the maximum risk allowed. The highest risk quotient for As was recorded along the river in Carletonville

(1.6) and the least in Carletonville formal (0.05). All points along the river were above the maximum allowable risk quotient 1. The risk quotient for As follows the same pattern as the concentrations, very high along the river and very negligible in the formal water sources. In terms of seasonal variation of the risk, the plot suggests that for informal water sources, such as in Carletonville, consumption of water poses a significant health risk from As both during the dry and wet seasons (1.18- 1.6). Whilst in Khutsong, the health risk from As is high during the dry season for Bekkersdal it is high during the wet season. Formal water sources have a minimal risk quotient during both seasons suggesting they are safe for consumption during both periods.

Using Pearson's correlation coefficient, an association was observed (R =0.564, p<0.05) between the As concentrations observed during the wet season and the occurrence of skin lesions. A slightly stronger association (R =0.681, p<0.05) was observed for As concentrations in the dry season. Similarly, evidence of risk of skin lesions from arsenic exposure in drinking water at concentrations less than 50 µg/Lwere reported in a longitudinal health study in Bangladesh (Ahsan et al., 2006). As concentrations in the range of 8.1-40.0 µg/L were associated with adjusted prevalence odds ratios of skin lesions of 1.91 at 95% confidence intervals. Ahsan et al., (2006) noted that the risk of skin lesions was also influenced by the body mass index (BMI), where the risk of skin lesions was inversely proportional to the BMI, which is reflective of the nutritional status. On the contrary, in another study in West Bengal India, on As concentrations in groundwater and its impacts on health, a majority of the people under study did not exhibit any skin lesions but their hair and blood samples contained elevated levels of As suggesting that they were sub-clinically affected (Chakraborti et al., 2002).

Table 10: Cross tabulation of skin lesions and gender

Gender		Suffered Skin lesions	
		Yes	No
Male	Count	20	54
	% within suffered skin lesions	41%	47.8 %
Female	Count	27	59
	% within suffered skin lesions	59%	52.2%

Table 10 shows the distribution of skin lesions with gender. There are variations in the risk of skin lesions based on gender, where 59%of the people who had suffered skin lesions were women as compared to 49% for men. Correspondingly, Haque et al., (2003) observed high prevalence in women relative to men. This was attributed to low privilege and poor malnutrition and the fact that usually women are more involved in household activities, thus more exposed to the contaminated water. The WFS catchment has been described to be rife with acute malnutrition and has been dubbed the HIV capital of South Africa (Stoch, 2008) hence consumption of water contaminated with As exacerbates the risk of developing skin lesions.

Cadmium (Cd)

Table 9 illustrates that the concentration (µg/L) of Cd during the wet season at all points in both formal and informal water sources was very negligible occurring at concentration of <0.1 compared to 3µg/L allowable limit by WHO and SANS. Thus, the recorded concentrations were well within the prescribed limits. Cd strongly adsorbs to the organic matter in the soil thus, it is present at low concentrations in the river.

Table 11: Mean and standard deviation values for cadmium

	Cadmium (µg/L)	
	Wet season	Dry season
Khutsong informal pt 1	<0.1	<0.1
Khutsong informal pt 2	<0.1	<0.1
Khutsong formal pt1	<0.1	<0.1
Carletonville informal pt 1	<0.1	<0.1
Carletonville informal pt 2	<0.1	<0.1
Carletonville Jojo tank 1	<0.1	<0.1
Carletonville Jojo tank 2	<0.1	<0.1
Carletonville formal pt 1	<0.1	<0.1
Bekkersdal informal pt 1	<0.1	<0.1
Bekkersdal informal pt 2	<0.1	<0.1
Bekkersdal standpipe 1	<0.1	<0.1
Bekkersdal formal	<0.1	<0.1
Guidelines (µg/L)		
SANS 241	3	
WHO	3	

Cd occurs mostly in association with Zn and gets into water from corrosion of Zn coated ("galvanized") pipes and fittings (danamark.com, 2008). At higher concentrations, Cd is potentially toxic. It replaces Zn biochemically and causes high blood pressure, kidney damage (Rajappa et al., 2010). The kidney is the critical target organ for exposed populations (Rajappa et al., 2010). Cd is known to accumulate in the human kidney for 20-30 years, and at high doses can it produce health effects on the respiratory system .Only 2% to 6% Cd is retained by the body on ingestion.

Based on the results, the concentrations of Cd suggest no immediate environmental and health hazards with respect to the water quality guidelines ,although evidence suggesting otherwise is beginning to surface . For example, using fish samples, the study by Kusch et al., 2008, revealed that chances of survival for the embryos at low concentrations around 0.2 - 2µg/L after a 36hours were low, and suggesting that low Cd concentrations may have a toxic effect at chronic exposures. Another study alludes to these findings; Cd concentrations of 2µg/L had an effect on the immune function of fish (Zelikoff, 1995).

Cobalt

Although the maximum admissible limit (MAL) of cobalt is not mentioned by WHO (2011), all the samples analyzed comply with the SANS 241 (500 µg/L) (Table 12). Generally, the concentrations of Co during the wet season were higher at many points compared to the dry season though within the acceptable limits of 500 µg/L by SANS. Cobalt has beneficial and harmful effects on the health. Cobalt solubility in water ranges from highly soluble to very insoluble thus it can contaminate water. For sufficient concentrations of Co it is beneficial because it is part of vitamin B and is also useful in the treatment of anaemia, but chronic exposures may lead to fibrosis of the lungs.

Table 12: Mean and standard deviation Values for cobalt

	Cobalt (µg/L)	
	Wet season	Dry season
Khutsong informal pt 1	10.5±0.5	7.6±2.02
Khutsong informal pt 2	9.1±0.5	9.5±1.1
Khutsong formal pt1	0.2±0	0.2±0
Carletonville informal pt 1	**30.8±0.15**	23.7±0.64
Carletonville informal pt 2	**31.8±0.96**	19.6±0.3
Carletonville Jojo tank 1	0.2±0	0.2±0
Carletonville Jojo tank 2	0.2±0	0.2±0
Carletonville formal pt 1	0.2±0	0.5±0.03
Bekkersdal informal pt 1	5.7±0.2	6.3±0.1
Bekkersdal informal pt 2	6.1±0.09	2.3±0.9
Bekkersdal standpipe 1	0.2±0	0.2±0.11
Bekkersdal formal	0.2±0	0.2±0
Guidelines (µg/L)		
SANS 241		500
WHO		not prescribed

The risk quotients for Co were subsequently higher in the dry season (Figure12), for points along the river compared to the formal water sources, but the values were well within the standards, whereby very low values were recorded in both the dry and wet seasons' asymptote to 0 in many cases. It can thus be concluded that there is no significant health risks for both the formal and informal settlement inhabitants, related to consumption of Co in their drinking water.

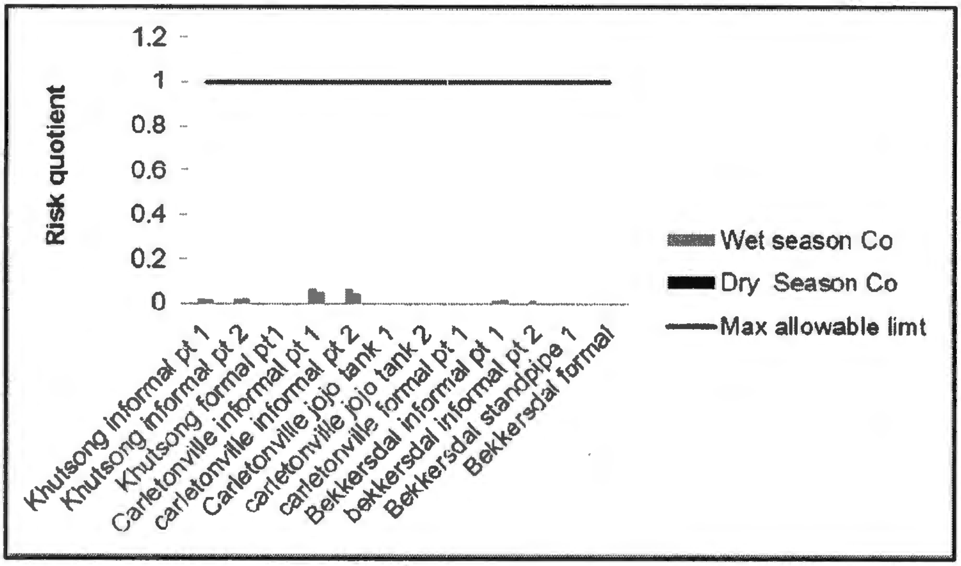

Figure 12: Cobalt risk quotient in the WFS

Lead (Pb)

In this study, during the wet season a maximum level of Pb (7.18±3.57 µg/L) was found in Carletonville tap water and the least (1.32±0.24 µg/L) in a Jojo tank in Carletonville (Table 13). However, Pb concentrations from all the sampling points were within the WHO and SANS 241 (2011) maximum allowable limit of lead in drinking water (10 µg/L) (Table 13). Begum et al., 2009 observed that alkaline pH leads to precipitation of Pb into water; in this study acidic pH was recorded for most of the samples during both seasons thus the low concentrations of Pb. These low concentrations of Pb could also be further attributed to the adsorption of metals to sediments, as a result of the intermolecular forces. Pb is the most significant of all the heavy metals because it is toxic, very common (Gregoriadou et al., 2001) and harmful even in small amounts. Thus, numerous studies have been conducted because of its hazardous effects (Mebrahtu and Zerabruk, 2011, Louis et al., 2003, Lanphear et al., 2000).

Table 13: Mean and standard deviation Values for lead

	Lead (µg/L)	
	Wet season	Dry season
Khutsong informal pt 1	2.3±0.2	1±0
Khutsong informal pt 2	2.8±0.6	1±0
Khutsong formal pt1	4.6±3.5	1±0
Carletonville informal pt 1	1.8±0.4	3.1±1.29
Carletonville informal pt 2	1.6±0.2	1.1±0.302
Carletonville Jojo tank 1	2.9±0.1	1.3±0.57
Carletonville Jojo tank 2	1.3±0.2	1±0
Carletonville formal pt 1	7.2±3.60	1±0
Bekkersdal informal pt 1	2.3±0.4	1±0
Bekkersdal informal pt 2	2.0±0.8	2.6±1.5
Bekkersdal standpipe 1	2.3±0.3	1.04±0.0750
Bekkersdal formal	3.16±1.02	1±0
Guidelines (µg/L)		
SANS 241	10	
WHO	10	

Pb has the ability to bio accumulate thus it is found in trace amounts in various foods, notably in fish, which are heavily subjected to industrial pollution. Most of the Pb consumed is removed from the bodies through urine; however, as exposure to Pb is cumulative over time, there is still risk of build-up, particularly in children. High concentrations of Pb in the body can cause death or permanent damage to the central nervous system, the brain, and kidneys (Hanaa et al., 2000).

Pb has been identified as the cause of brain and kidney damage. At concentrations of 10µg/dL harmful effects on children's learning and behaviour have been reported (Lanphear et al.,2000.In the WFS, the health risk arising from Pb are minimal since the risk quotients obtained during both seasons from all the sampling points were well within maximum allowable risk limit (Figure 13).

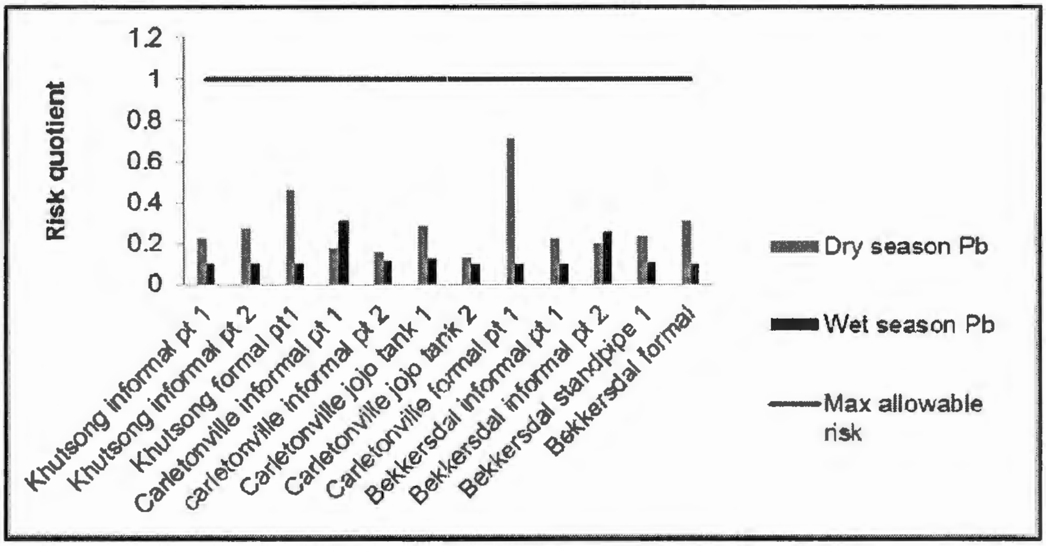

Figure 123: Lead risk quotient in the WFS

Zinc

Results of Zn concentrations are presented in Table 14. During the wet season, the concentrations of Zn were generally within the prescribed limit of drinking water from SANS 241. The concentrations were higher in formal water sources compared to the informal, with the highest recorded value obtained in Carletonville tap water (266 µg/L)and the least in Khutsong along the river (10.0 µg/L). The higher concentrations in the formal water sources may be attributed to dissolution of the Zn component in taps (WHO, 2011).For the informal settlements, samples along the river ,recorded lower concentrations , this can be attributed to the acidic pH values along the river which resulted in adsorption of Zn onto the sediments(Begum et al., 2009). In terms of seasonal variability where Zn concentrations were higher in the wet season relative to the dry season can also be explained by the pH,whereby during the wet season, the rains shift pH of the water from acidic to alkaline ,resulting in the precipitation of Zn into the water column (Begum et al., 2009).

Table 14: Mean and standard deviation values for zinc

Sampling point	Zinc (µg/L)	
	Wet season	Dry season
Khutsong informal pt 1	20.8±1.6	<0.60
Khutsong informal pt 2	10.0±0.7	<0.60
Khutsong formal pt1	50.6±24.6	<0.60
Carletonville informal pt 1	19±0.8	<0.60
Carletonville informal pt 2	19.6±1.4	<0.60
Carletonville Jojo tank 1	21.3±1.1	<0.60
Carletonville Jojo tank 2	21.5±3.	<0.60
Carletonville formal pt 1	266±231.15	<0.60

Bekkersdal informal pt 1	21.5±2.8	<0.60
Bekkersdal informal pt 2	19.96±0.4	<0.60
Bekkersdal standpipe 1	172.7±0.6	133.3
Bekkersdal formal	65.2±1.3	116.7
Guidelines (µg/L)		
SANS 241	5000	
WHO	Not prescribed	

Because many samples in the dry season recorded Zn concentrations well below the detection limit, the health risks arising from consumption of drinking water at the current levels are very negligible as is illustrated in the plot for the risk quotient (Figure 14). Many points recorded risk quotients equalling zero during both the dry and wet seasons, and the highest risk quotient was a very negligible 0.04 µg/L observed in Carletonville tap water.

Zn is a microelement that plays a role in the biosynthesis of nucleic acids and is involved in the healing process of the body. Zn is relatively non-toxic such that humans and animals exhibit tolerance at high intake (Tran, 2008). The adverse effects related to Zn have been noted for concentrations ranging between 100-300 mg/day, with effects like the reduction of copper in the body thus inhibiting the action of certain enzymatic functions (Eby and Halcomb, 2006). No evidence exists on the association between Zn and human carcinogenesis, either genotoxic or even teratogenic (Udeh, 2004). At its present concentrations in drinking water, one can conclude that Zn poses no health risks to communities in the WFS catchment (Figure 14).

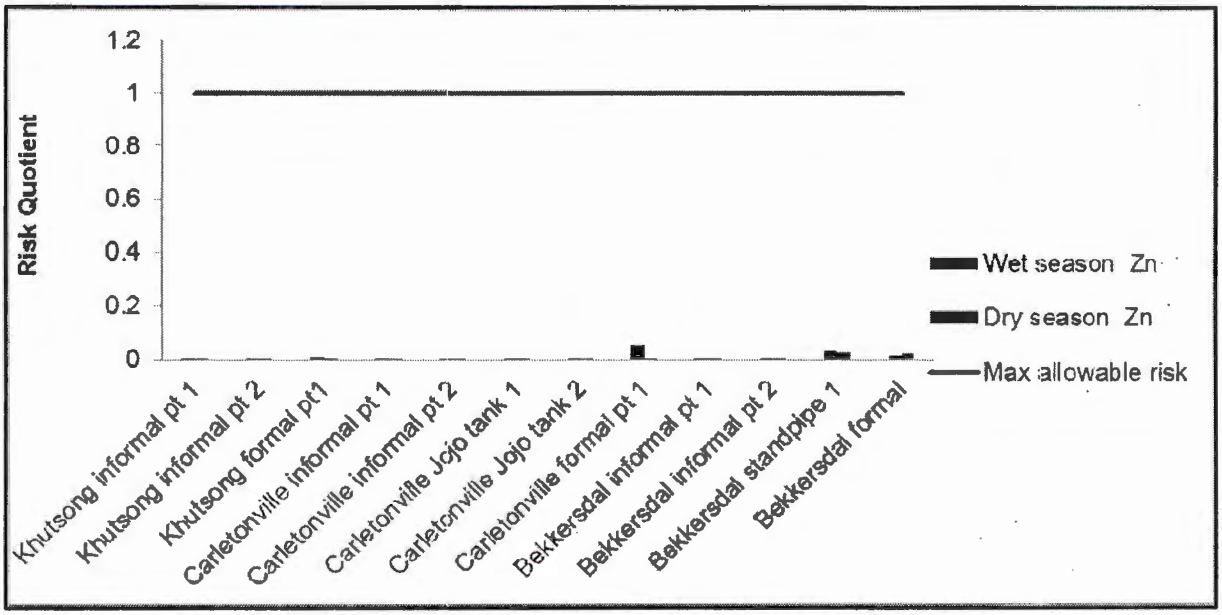

Figure 14: Zinc risk quotient in the WFS

4.2.4 Uranium Radioisotopes

Uranium (U) is one of the hazardous substances that evoke two different and totally unrelated effects, one due to its radioactivity and the other due to its chemical nature (Anderson et al., 2012).It has a low specific radioactivity and an extremely long half-life of 4.5 billion years, (Brugge et al., 2011).In this study, only two isotopes of U were determined U^{235} and $U^{238}$and results of their mean concentrations are shown in Table 15.

The chemical concentrations of both U^{235} and U^{238} followed the same trend as As, high along the river and very low in the formal water sources. The highest concentration forU^{235} andU^{238}being 62.3 µg/L and 59.9 µg/L respectively and the lowest being 0.2 µg/L and <0.2 µg/L respectively. Along the river in Khutsong, both isotopes were very high in the dry season and falling within the standards during the wet season. In Carletonville along the river, both isotopes recorded very high concentrations throughout the dry and wet seasons (ranging between 51 µg/L and 59.9 µg/L). In Bekkersdal, all the points were in excess of the standards with the highest U isotope concentrations observed during the dry season relative to the wet season. These high values along the river could be attributed to the discharge of acidic mine water. Spatially the concentrations were high at points which are close to many mines, refer to Figure 2.

Table 15: Mean and standard deviation values for uranium

	Uranium (µg/L) 235		Uranium 238(µg/L)	
	Wet Season	Dry Season	Wet Season	Dry Season
Khutsong informal pt 1	8.5±0.2	**52.7±0.6**	8.483±0.18	**56±0**
Khutsong informal pt 2	8.3±0.2	**56±9.6**	8.4±0.46	**57.7±7.2**
Khutsong formal pt1	0.2±0.005	0.3±0.1	<0.2±0	0.3±0.05
Carletonville informal pt 1	**51.2±1.4**	**53.7±2.1**	**57.9±1.51**	**56.3±2.5**
Carletonville informal pt 2	**59±1.5**	**48.3±0.6**	**59.9±0.7**	**51±1**
Carletonville Jojo tank 1	0.2±0.006	0.3±0.02	0.22±0.01	0.28±0.03
Carletonville Jojo tank 2	0.2±0.005	0.31±0.08	<0.2±0	0.26±0.01
Carletonville formal pt 1	0.2±0.005	7.8±13.14	0.207±0.012	0.21±0.021
Bekkersdal informal pt 1	**22.4±0.056**	**62.3±1.16**	**22.6±1.06**	**63±1**
Bekkersdal informal pt 2	**23.1±0.5**	11.7±0.55	**23.2±0.61**	12.±0.67
Bekkersdal standpipe 1	0.2±0.006	0.277±0.04	0.27±0.02	0.3±0.012
Bekkersdal formal	0.2±0.006	0.25±0.05	0.2±0.02	0.24±0.04
Guidelines (µg/L)				
SANS 241				15
WHO				30

An independent t test was carried out to determine whether the risk was more significant in either of the seasons. Results revealed no statistically significant difference between the mean concentrations for both isotopes in the two seasons at 95 % confidence interval (t =0 .319 for U^{235} and t= 0.365 for U^{238}) (Appendix 4).

To understand better the magnitude of chemical effects that U has on the health of the WFS catchment communities, computation of the risk quotient was done for U235 and U238 (Figure 15 and 16).

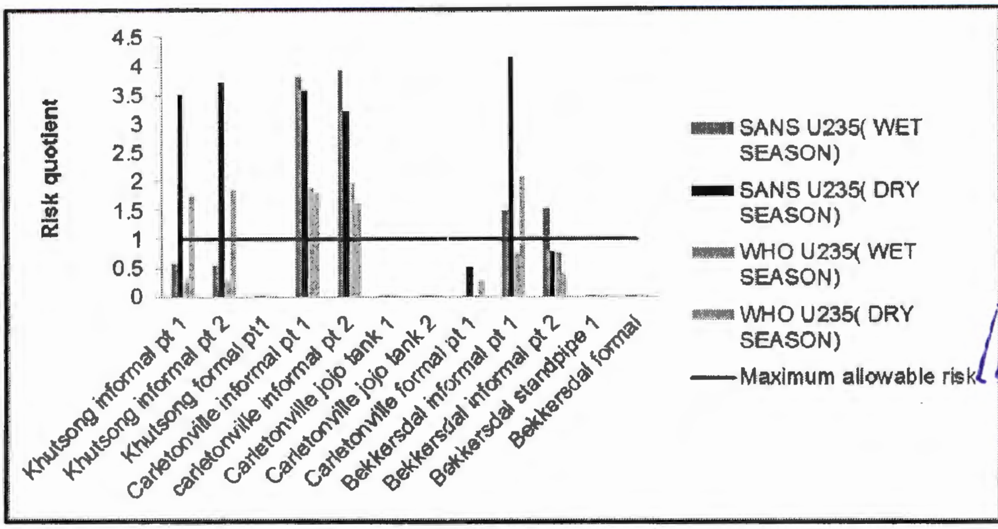

Figure 15: U^{235} risk quotient in the WFS

The chemical effects of U are of significance because U and its compounds are highly toxic substances, and as such, they are most soluble in body fluids. Thus, its chemical effects to the human body on inhalation, ingestion or absorption through the skin are more likely than radiation damage. Although there was no seasonal statistically significant difference in the risk and the mean U concentrations for both isotopes (Appendix 6, Tables 28 and 29).Findings from other studies revealed that U concentrations are higher during the wet season (Blowes et al., 1994; Pinto et al., 2004;Schemel et al., 2000) this was attributed to the colloidal transport as well as the high flow of water which results in large volumes of water interacting with low grade ore and waste rock.

In this study, the insignificant difference in U concentrations which were slightly higher in the dry season could be attributed to the fact that during the wet season there were rainfall events, which caused the dilution of the concentrated pollutants or possibly the fact that, the stormy rainfall events which occurred during the dry season, could have caused the resuspension of sediments thereby reintroducing pollutants in the water column. On the contrary, there was a statistically significant difference in the concentrations for both isotopes U^{235} and U^{238}between the formal and informal settlements (t=0 for both U^{235} and U^{238}) at a 95% confidence interval. Results suggest that informal settlements are at a higher risk of consuming water contaminated by U^{235} and U^{238}.

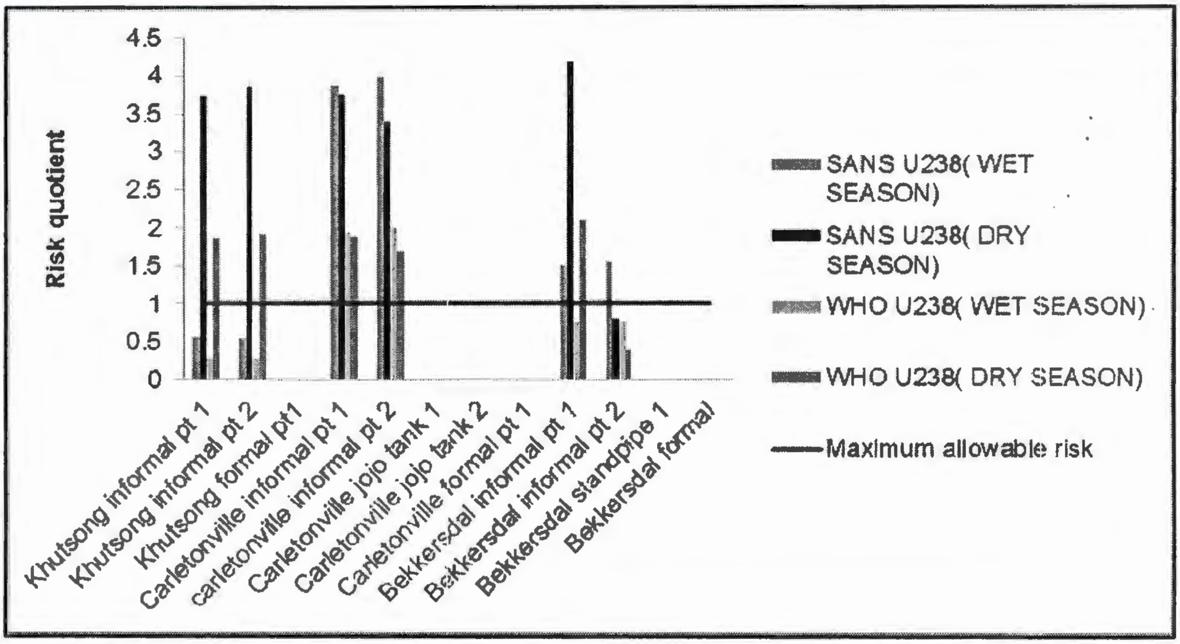

Figure 16: U^{238} risk quotient in the WFS

Miller et al., 2002 observed that uranyl ions exhibited genotoxic effects at low concentrations causing genetic damage to cell cultures. In other studies, (Zaire et al., 1998, Schroeder 2003) anomalous health effects like kidney and lung inflammation were reported, but these were noted to defy the conventional radiological risk models since they occurred at very low concentrations where alpha particle releases were negligible. In a study on the biochemical and biophysical aspects of exposure to U it was suggested that the reason could be the synergistic mechanisms of the radiation and chemistry (Busby and Schnug, 2007). There is also evidence to the effect that U toxicity increases with the presence of Cd.

Calculation of radiological annual doses was used to estimate the absorbed radiation from ingestion of contaminated drinking water. According to Chau and Michalec, (2009), radiological annual dose is the annual dose rate caused by absorption of natural radioactive elements in water, based on the assumption that a man drinks **N** litres per year using Equation (1) as stated in the WHO Drinking water guidelines (1998). Figure 17 shows the calculated annual radiological dose for U^{235} in the WFS during the wet season sampling.

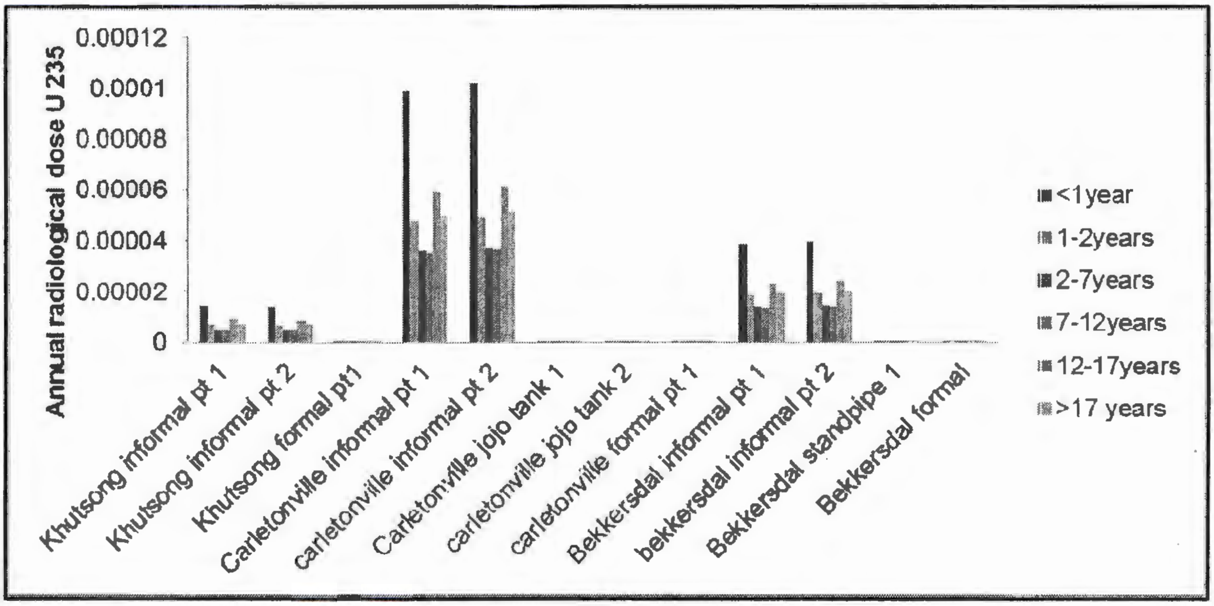

Figure 17: Annual radiological dose for U235 in WFS (wet season)

The highest recorded radiological dose for U^{235}during the wet seasonwas observed in Carletonville along the river (9.92×10^{-5} mSv/yr) and this was for the category of less than a year. The lowest observed was in Khutsong formal and Carletonville Jojo tank which both recorded 1.23×10^{-7} mSv/yr for the category of 7-12 years.

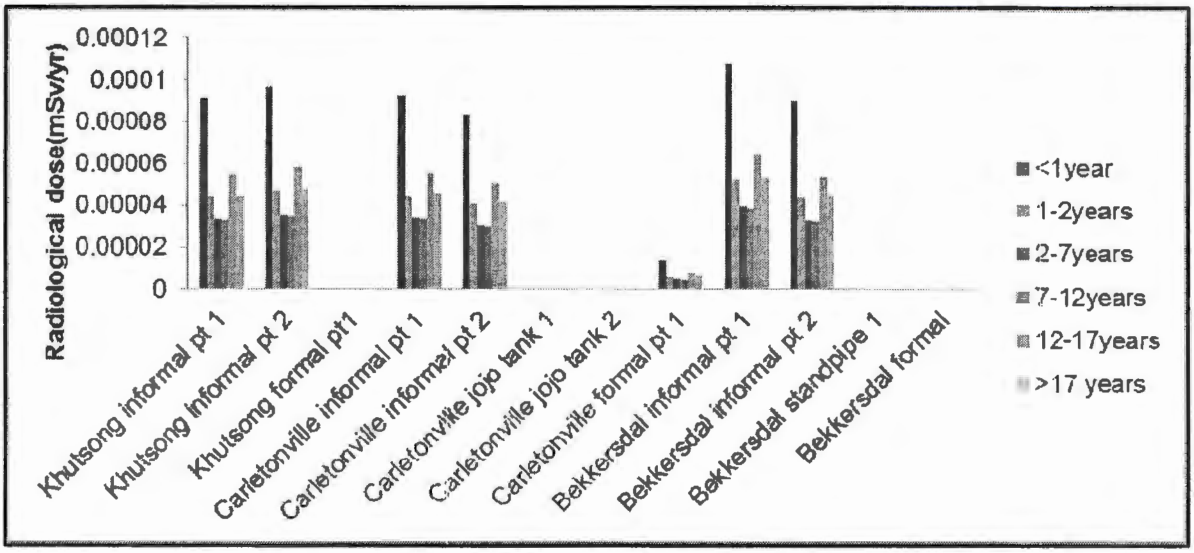

Figure 18: Annual radiological absorbed dose U^{235} in the WFS (dry season)

During the dry season, the radiological absorbed dose for $U^{235}$the maximum was observed in Bekkersdal (1.062×10^{-4} mSv/yr) for the category of <1year (Figure 18) and it should be noted that compared to the wet season the radiological absorbed dose at all points along the river for infants (<1year) was higher in the dry season. The least observed during the dry season was from Carletonville jojo tank which recorded 1.19×10^{-7} mSv/yr for the category of <1year.All the sampling points were within the WHO 2011 and SANS 241(2011) standard which is pegged at 0.1 mSv/yr for U^{235} for both seasons.

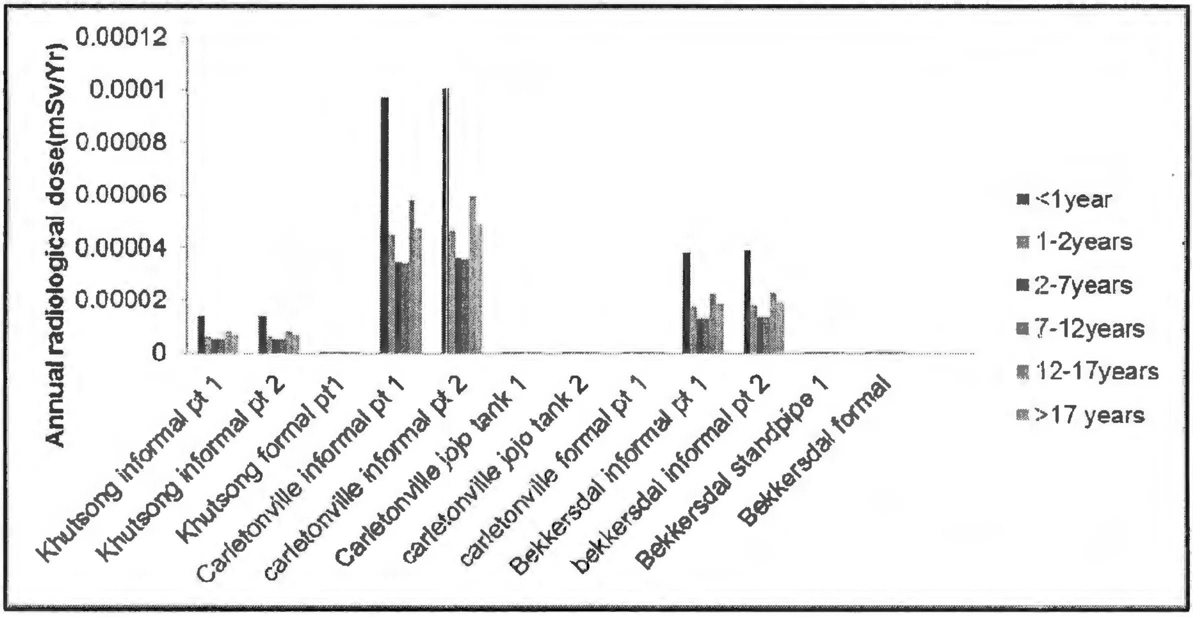

Figure 19: Annual radiological dose U^{238}(wet season)

The highest recorded radiological dose forU^{238} during the wet seasonwas observed in Carletonville along the river (1.01×10^{-4} mSv/yr) and this was for the category of<1year. The lowest observed was in a Carletonville jojo tank, which recorded 1.18 $\times 10^{-7}$ mSv/yr for the category of 7-12 years (Figure 19).For the dry season the radiological absorbed dose for U^{238} was at its highest in Bekkersdal (1.06×10^{-4} mSv/yr) this was for the category of <1year (Figure 20). The least observed dose for U^{238}during the dry season was from Carletonville tap water which recorded 1.279×10^{-7} mSv/yr for the category of <1year. All the sampling points were within the WHO 2011 and SANS 241(2011) standard which is pegged at 0.1mSv/yr for U^{235} for both seasons.These results imply that the age group of <1year are at the highest risk of contracting diseases arising from the consumption of U contaminated water like, kidney and lung inflammation (Zaire et al., 1998,Schroeder 2003),since they recorded the highest dose in both seasons, but it suffices to mention that although the dose was well within the standards, Busby, 2009 reported increases in infant leukemia from low dose exposure to U.

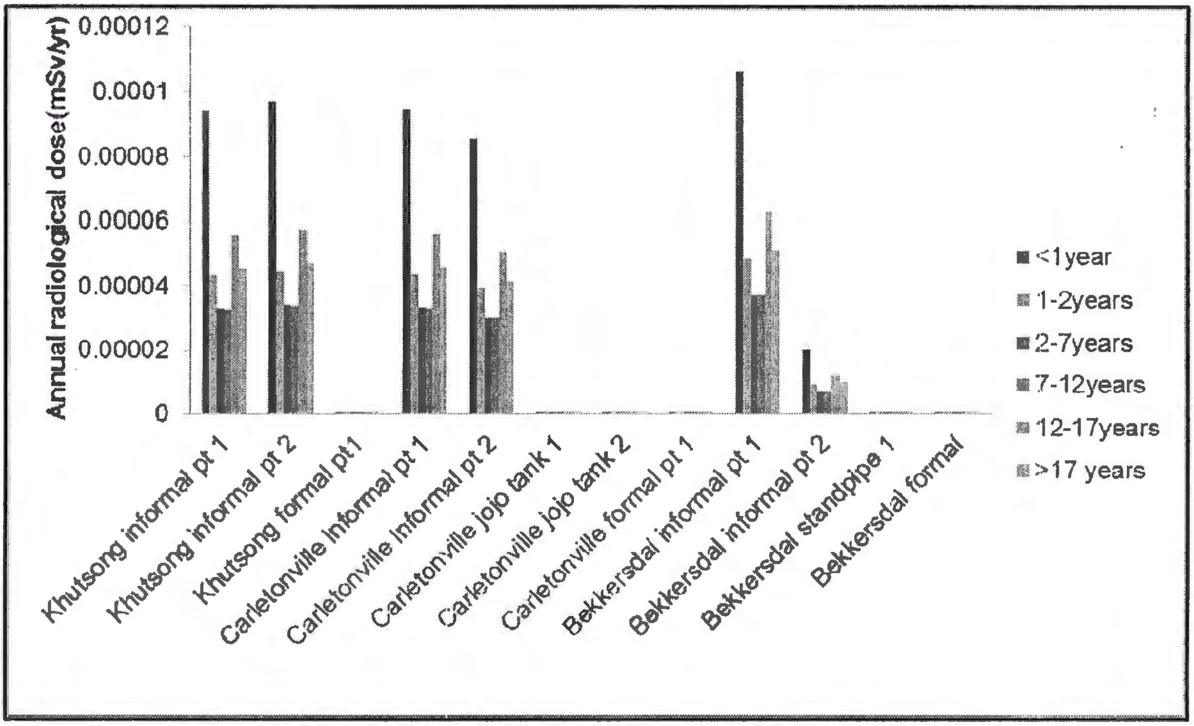

Figure 20: Annual radiological absorbed dose U^{235} (dry season)

In a similar study Karamanis et al., 2007 analysed radioactivity in bottled mineral water in Greece. Results revealed that the contribution of U to the internal exposure of adults from the consumption of mineral water with the maximum determined activity was 0.77 × 10–3 mSv/yr. This value increased by a factor of 2.7, 1.8, 1.5 and 1.5 for the age groups of 1–2, 2–7, 7–12 and 12–17, respectively. Similar findings were obtained by Zamora et.al, (2009) from a study in an aboriginal community in Australia. The highest dose of uranium calculated was 2.1 mSv and this was the cumulative dose over a 15-yearperiod. The study concluded that the risk of cancer was 13 in 100 000 which was insignificant for the population size studied meaning that chemical toxicity would be a greater health concern than the radiation dose. Based on the annual dose concentrations for U^{235} and U^{238} from the current study, similar conclusions can be drawn (Figures 17-20).

Cancer risk

In order to determine whether there is a significant risk from radiation properties of U a life time cancer risk for mortality and morbidity was computed based on U activity in water for both seasons using Equation (3). Table 16 shows the cancer mortality and morbidity for U^{235} and U^{238} during the wet season.

Table 16: Cancer mortality and morbidity for U^{235} and U^{238} (wet season)

	Cancer mortality risk U^{235}	Cancer mortality risk U^{238}	Cancer morbidity risk U^{235}	Cancer morbidity risk U^{238}
Khutsong informal pt 1	9.23×10^{-6}	8.57×10^{-6}	1.43×10^{-5}	1.31×10^{-5}
Khutsong informal pt 2	8.94×10^{-6}	8.51×10^{-6}	1.39×10^{-5}	1.30×10^{-5}
Khutsong formal pt1	2.16×10^{-7}	2.02×10^{-7}	3.36×10^{-7}	3.10×10^{-7}
Carletonville informal pt 1	6.19×10^{-5}	5.85×10^{-5}	9.61×10^{-5}	8.96×10^{-5}
Carletonville informal pt 2	6.39×10^{-5}	6.05×10^{-5}	9.92×10^{-5}	9.27×10^{-5}
Carletonville jojo tank 1	2.49×10^{-7}	2.22×10^{-7}	3.87×10^{-7}	3.40×10^{-7}
Carletonville jojo tank 2	2.16×10^{-7}	2.02×10^{-7}	3.36×10^{-7}	3.10×10^{-7}
Carletonville formal pt 1	2.20×10^{-7}	2.09×10^{-7}	3.41×10^{-7}	3.20×10^{-7}
Bekkersdal informal pt 1	2.42×10^{-5}	2.28×10^{-5}	3.77×10^{-5}	3.50×10^{-5}
Bekkersdal informal pt 2	2.50×10^{-5}	2.34×10^{-5}	3.88×10^{-5}	3.58×10^{-5}
Bekkersdal standpipe 1	2.67×10^{-7}	2.73×10^{-7}	4.15×10^{-7}	4.17×10^{-7}
Bekkersdal formal	2.46×10^{-7}	2.36×10^{-7}	3.82×10^{-7}	3.61×10^{-7}

Results indicate that during the wet season, highest cancer mortality risk is from U^{235} which was 6.19×10^{-5}noted in Carletonville along the river and least from U^{238} (2.73×10^{-7}) observed for Bekkersdal standpipes. Whilst the cancer morbidity risk was the highest for U^{235} in Carletonville informal settlements and the least was for U^{238} for Carletonville Jojo tanks.

The cancer mortality and morbidity risk for U^{235} and U^{238} during the dry season was generally higher relative to the wet season (Table 17).

Table 17: Cancer mortality and morbidity for U^{235} and U^{238} (dry season)

	Cancer mortality risk U235	Cancer mortality risk U238	Cancer morbidity risk U235	Cancer morbidity risk U238
Khutsong informal pt 1	5.70×10^{-5}	5.65×10^{-5}	8.85×10^{-5}	8.64×10^{-5}
Khutsong informal pt 2	6.06×10^{-5}	5.83×10^{-5}	9.41×10^{-5}	8.92×10^{-5}
Khutsong formal pt1	3.57×10^{-7}	3.10×10^{-7}	5.55×10^{-7}	4.74×10^{-7}
Carletonville informal pt 1	5.81×10^{-5}	5.69×10^{-5}	9.02×10^{-5}	8.71×10^{-5}
Carletonville informal pt 2	5.23×10^{-5}	5.15×10^{-5}	8.12×10^{-5}	7.89×10^{-5}
Carletonville jojo tank 1	2.99×10^{-7}	2.83×10^{-7}	4.65×10^{-7}	4.33×10^{-7}
Carletonville jojo tank 2	3.35×10^{-7}	2.63×10^{-7}	5.21×10^{-7}	4.02×10^{-7}
Carletonville formal pt 1	8.48×10^{-6}	2.19×10^{-7}	1.32×10^{-5}	3.35×10^{-7}
Bekkersdal informal pt 1	6.74×10^{-5}	6.37×10^{-5}	1.04×10^{-4}	9.75×10^{-5}
Bekkersdal informal pt 2	5.63×10^{-5}	1.22×10^{-5}	8.75×10^{-5}	1.86×10^{-5}
Bekkersdal standpipe 1	2.99×10^{-7}	2.69×10^{-7}	4.65×10^{-7}	4.13×10^{-7}
Bekkersdal formal	2.71×10^{-7}	2.43×10^{-7}	4.20×10^{-7}	3.71×10^{-7}

During the dry season, highest cancer mortality risk was from U^{235} that was 6.74×10^{-5} noted in Bekkersdal along the river and least from U^{238} (2.43×10^{-7}) observed for Bekkersdal tap water samples. Conversely, the cancer morbidity risk was the highest for U^{235} (1.04×10^{-4}) in Bekkersdal along the river and the least was for U^{238} for Carletonville tap water (3.35×10^{-7}). Based on Ye-shin et al., 2004 study, the results reflect no significant radiological risk from both isotopes of U in the WFS during the wet and dry seasons, since all the values recorded are lower than 10^{-3}.Similar findings were observed in a study on the chemical and radiological risk assessment of U in borehole water in Nigeria (Amakom and Jibiri 2010) with the magnitude of radiological cancer risks in range of 10^{-4}.

In addition, an association was observed between the occurrence of kidney problems and the average U^{235} and $U^{238}$for the two seasons using Pearson's correlation coefficient ($r=0.68$ and 0.691 respectively $p<0.001$).These findings only serve to confirm the conclusion reported by Amakom and Jibiri 2010, that the chemical properties of U are more likely to cause health effects compared to radiological in the WFS catchment.

Summary

In this chapter, findings on the water sources and quality in the WFS catchment have been presented. The quality of water in the formal settlements vis-à-vis formal water sources is generally in line with the SANS 241 and the WHO 2011 drinking water standards relative to the informal water sources in particular river water. The elements of concern in terms of health are As and U^{235} and U^{238} which are very high along the river and in excess of the standards. Significant health effects from U are likely to arise from its chemical properties rather than its radiological properties or the synergistic effect of the two. Since no statistically significant seasonal variability was observed, it can be concluded that those consuming water along the river, are equally at risk of contracting water related diseases in both the dry and wet seasons. The following chapter deals with dynamics involved in access to potable drinking water based on various stakeholder perceptions and the water institution in South Africa.

CHAPTER 5

5 STAKEHOLDERS PERCEPTIONS AND THE WATER INSTITUTION IN SOUTH AFRICA

This chapter focuses on the perceptions relating to water resources management in the WFS catchment area; in particular, issues surrounding access to clean water. The perceptions of various stakeholders including the communities, municipalities and mines are taken into consideration. There is discussion regarding the municipality and community measures to alleviate problems of water shortages and water quality. Using various indices developed in the study, an examination of the different dynamics that influence perception are revealed. There is also a critical analysis of the South African water institution and its implementation using the Wonderfonteinspruit catchment as a case study.

5.1. Community Perceptions

Community perceptions regarding water resources management have very important implications as they empower water utilities providers to improve their services and at the same time they limit the ability to make changes. The purpose of using community perceptions in studies like this one is they are reflective of the water resources goals of a catchment. Public perceptions also contribute to multi-stakeholders processes, help eliminate discontentment and promote cooperation with the consumers (De Franca Doria 2010).

In this study, the focus was on community perceptions of the following;

- municipal measures and programs to curb water shortages and provide quality water ;
- quality of water(its suitability for drinking, cooking and other domestic uses)
- Effectiveness of the municipal programs and measures
- The knowledge of water related disease especially those endemic to the WFS catchment

5.1.1 Provision of portable water by the Municipalities

The distribution of residents relative to the perception on ability of the municipality to provide adequate potable water is as shown in Table 18.

Table 18 : Municipality measures to ensure adequate potable water supplies

Municipal efforts	%
Nothing	45
Borehole	0
Protected wells	0
Tanks	5.6
Other	49.4

A staggering 45 % stated that the municipality was not doing anything. In contrast, only 5.6 % stated they were provided with tanks. 49.4% responded that the municipality had other measures, for instance the municipality made them aware of pending water shortages so that they could store water in advance whilst others stated that the municipality was already providing them with sufficient potable water.

From the phenomenon of IWRM, providing access to potable water requires participation from all stakeholders. The respondents were asked on how much they are contributing to ensure access to clean water. Table 19 shows community intervention measures within the WFS catchment.

Table 19: Community Measures to ensure they access sufficient potable water

Community measures	%
Nothing	51.9
Reported to the chief	0.6
Formed water committee	3.1
Reported to municipality	18.1
Other	11.9
Committee and municipality	14.4

The community also tries to intervene in different ways. Despite 51.9% doing nothing, 0.6 have reported to the chief, while a total of 25.6% either formed a water committee or reported to the municipality or did both. The other measures (11.9%) comprised of conservation and use of river water to augment the meager supplies.

5.1.2. Suitability index

A **suitability index** ranging from 0 to 4 (very unsuitable to very suitable) based on the composite responses was devised and the results presented in Figure 21. This suitability index can be defined as a quantitative measure of perception, regarding the appropriateness of water for its domestic uses. It is a useful functional tool for assessment of community awareness and attitudes towards water quality management (Marara et al., 2011).To determine the perception on suitability of water for domestic consumption, for all the domestic uses of water, the residents were asked if they thought the water was suitable for, drinking, cooking, bathing and laundry.

Figure 21 presents the suitability index for domestic water use by settlement. Results show that the suitability index varies with settlement type where 98.75% in the formal settlements perceived that the water was very suitable for all the domestic uses compared to 61.25 % in informal settlements. Generally, the magnitude of perceived risks from tap water is very small (Anadu and Harding 2000) thus tap water is considered to be very safe. This explains the majority of formal residents perceiving their water to be very suitable relative to informal residents because formal settlements have access to municipal (tap) water, which they assume is clean and some of the informal settlements access water from the formal settlements.

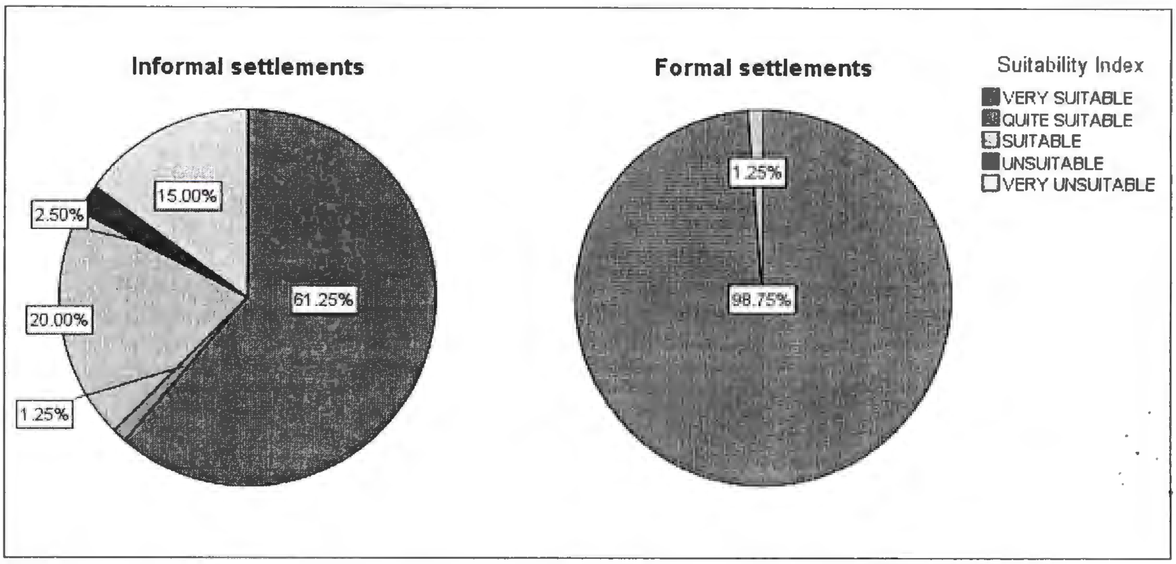

Figure 21: Suitability index for domestic water use by settlement type

Only 17.5% in informal settlements perceive the water to be unsuitable since they have to use water from the river for all domestic purposes. Of much interest to note were the responses from some residents in the informal settlement (9%) who indicated that the river water they were using was suitable for all domestic purposes because they had been using it for a while with no visible health effects. This is in agreement with findings from a study on perceptions on drinking water in Colorado where it was noted that organoleptics (taste, odour and colour) have a large influence on public perception of water quality compared to other factors like media coverage (De Franca Doria 2010). Even though there has been a lot of media coverage on the contamination of the WFS, the influence of these reports on WFS communities' perception of the water quality was very limited because to them the water looks clean, its taste is palatable and it does not have odour, hence suitable for domestic consumption.The majority of those who perceived the water unsuitable for domestic use were residents of Khutsong and Carletonville (Figure 22). Of the total population of respondents,which can be evenly distributed to 25 % for each settlement,a majority of people perceived the water to be very suitable Bekkersdale 24%,Kagiso 22% ,Carletonville 16% and Khutsong 15%.

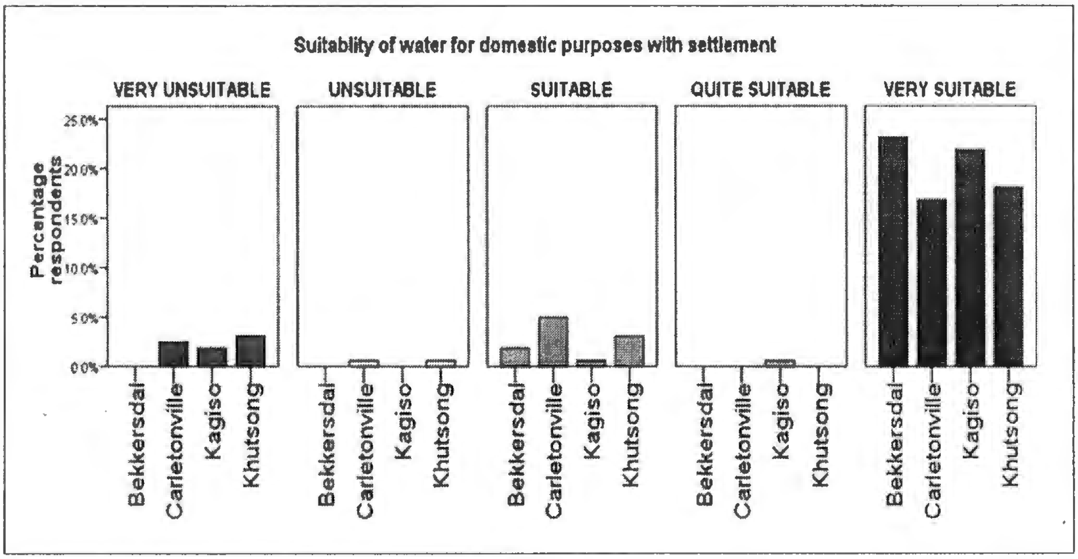

Figure 22: Suitability index for domestic water use by settlements

There are several ways that water can be made safe at household level. Some of the methods include boiling; where micro-organisms exposed to high temperature can be killed; filtering can eliminate some microbes as well as removing suspended solids. The study revealed that about 91.3% of the respondents do not pre-treat their water for drinking) and cooking (95.6%). However, only 3.1 % reported pre-treating their water by boiling before drinking and cooking, whilst 1.3% leaves the water for cooking to settle compared to 3.8% for drinking water (Figure 23).

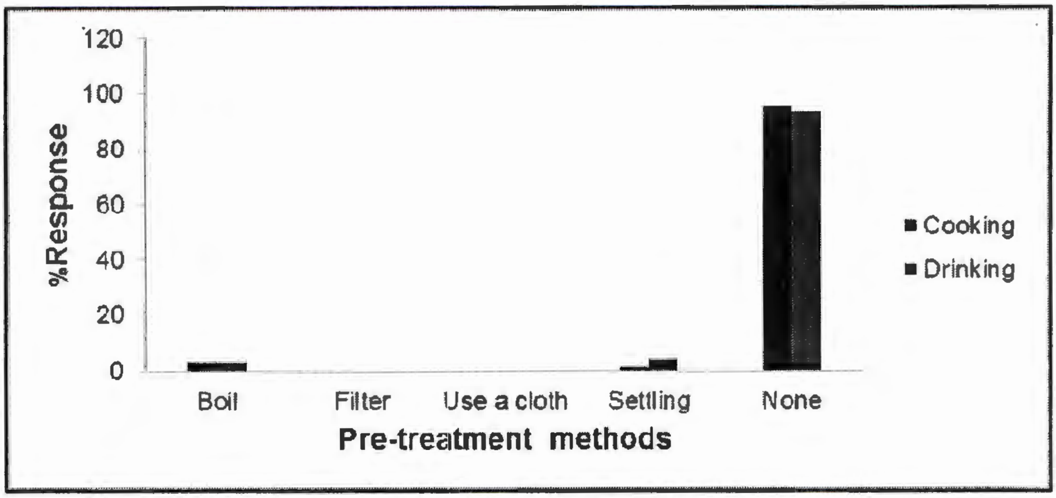

Figure 23: Pre-treatment methods for drinking and cooking water

5.1.3. Effectiveness index

To determine the perception on effectiveness of municipal efforts, a composite measure termed the **effectiveness index** was devised based on responses to sufficiency and efficiency of municipal measures. An effectiveness index is a quantitative measure of perception regarding the sufficiency and adequacy of municipal intervention methods during periods of water scarcity and events of poor water quality (Marara et al., 2011). This is a functional tool for determining municipal programs on water demand management as well as integrated water resources management. The effectiveness index ranges from 0 to 2 (ineffective to very effective). The results are presented in Table 20.

Table 20: Effectiveness index: Water shortages and water quality

Variable	Response	Effectiveness Index		
		Ineffective (%)	Effective (%)	Very effective (%)
Water shortage	Yes	30.6	2.5	18.1
	No	5.6	1.3	41.9
Water quality	Yes	22.5	1.3	6.9
	No	13.8	2.5	53.1

Results show that majority of the respondents perceive the intervention as very effective and this constituted 41.9% who had no problems of water shortages and 53.1% who had no problems of water quality. In contrast, 43.1 % felt that municipal efforts were ineffective, and they largely comprised those with problems of water shortages (30.6%) as well as water quality (22.5%) suggesting possible associations between water quality and water shortage problems with perception on effectiveness.

Using Pearson's Chi-Squared test, the relationship between perception on effectiveness of municipal efforts and the existence of water quality problems was computed. Results from the test revealed an association (r= 0.43, $p<0.001$) between perception on effectiveness of municipal intervention and the existence of water quality problems. This implies that the higher the existence of water quality problems, the higher the probability that residents would think the municipality efforts is ineffective.

Another association was also found between effectiveness of municipal intervention and the occurrences of water shortages (r=0.46, $p<0.001$). From these results, it can be concluded that, communities' perception on effectiveness is determined by availability of water as well as the quality of the water. Perception on effectiveness of municipal intervention increases with availability of water.

5.1.4. Disease awareness index

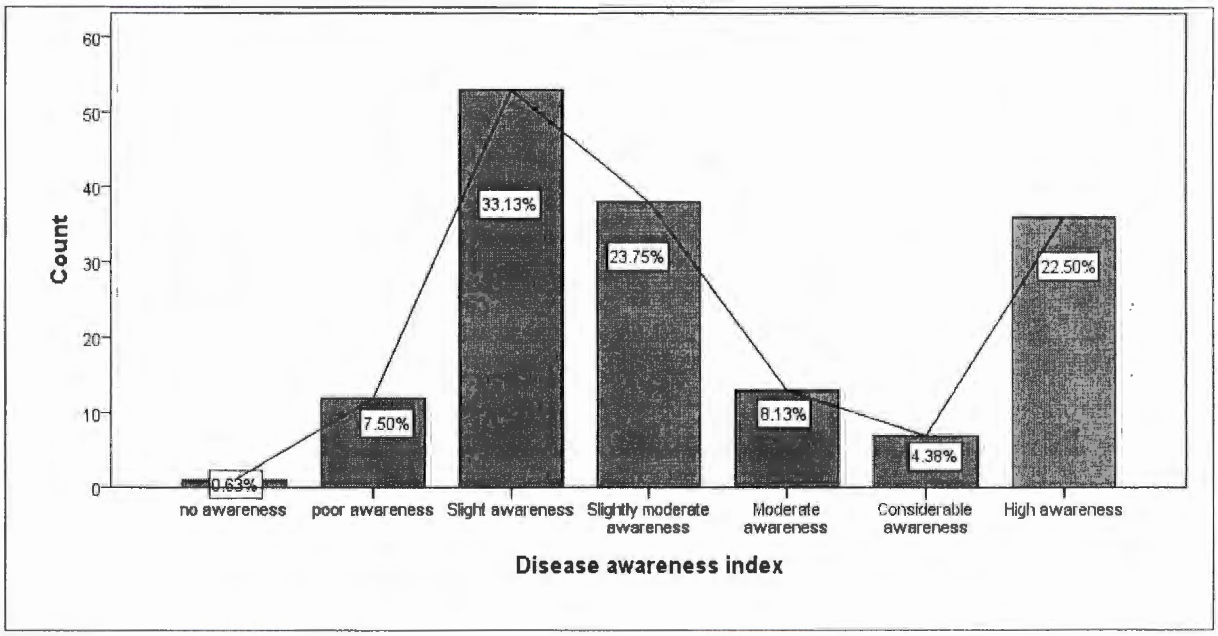

Figure 24: Disease awareness index

All the respondents were well aware of the importance of water quality in general regardless of their level of education, existence of health education, and settlement type. An index was created based on their knowledge of water quality diseases to determine the various degrees of awareness. The results are illustrated in Figure 24.

The disease awareness index almost follows a normal distribution. The frequency of awareness increases with increasing awareness and reaches a peak where 33.13% are slightly aware of water quality diseases, the frequency then decreases with increasing disease awareness (moderate- considerable).

There was generally some awareness of diseases related to water quality. A significant proportion of those who were aware come from the respondents (58.7%) who stated that they did not have any health education given to them compared to 33.1% who were aware but had some health education (Table 21).

Table 21: Disease awareness index and health education

Disease awareness index	Health Education	
	Yes (%)	No (%)
No awareness	0	0.6
Poor awareness	1.3	6.3
Slight awareness	12.5	20.6
Slightly moderate awareness	8.1	15.6
Moderate awareness	2.5	5.6
Considerable awareness	2.5	1.9
High awareness	7.5	15

It was important to ask respondents' prevalence of water quality related diseases in the area. The survey revealed that people in the area suffer from a number of diseases including diarrhoea, skin cancer and kidney damage as the three most serious diseases (Table 22). However, 16% of the respondents indicated other diseases such as HIV, TB and cow worms as endemic in the area. This conforms to the findings by Stoch (2008) who stated that areas, for example, Carletonville are HIV 'havens".

Table 22: Endemic water quality diseases

Diseases	%
Cholera	9
Diarrhoea	27
Skin cancer /rushes	16
Kidney damage	14
Lung cancer bladder problem	8
bladder problem	2
Other	16(HIV, TB and cow worms)
Don't know	48
None of the above	3

Figure 25 shows the distribution of respondents according to the diseases suffered. A significant 46% of the respondents stated that they had not suffered any water related diseases, 29% had suffered from skin cancers, followed by pigmentation changes that recorded (12%) and kidney problems 9%.Other forms of cancer recorded only 1%.

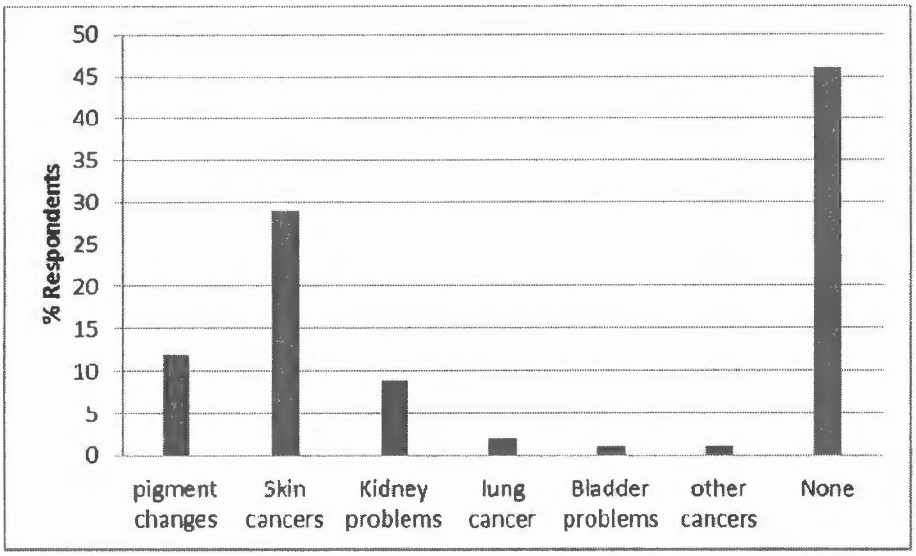

Figure 25: Water quality related diseases suffered by interviewees

5.2. Municipality survey

The results of this survey are presented in two main categories; the water sources and uses and the water institution for all the three municipalities; Merafong (Carletonville and Khutsong), Westonaria (Bekkersdal) and Mogale (Kagiso, Krugersdop, Rietvallei).

5.2.1. Water sources and uses

Across all the municipalities in the scope of the study, the main water source is the Rand water board. In Merafong the other main water source are boreholes and in Mogale the other main water source are rivers and dams. Water from the Rand water board goes into the main distribution network of all the three municipalities and is used for domestic purposes such as cooking, drinking, bathing and laundry and even recreational activities in the case of swimming pools.

In the case of rivers and dams, the water is used specifically for agricultural purposes; although some municipalities in particular Merafong and Westonaria acknowledge that their residents resort to river water and use it for bathing and laundry. In municipalities like

Merafong and Mogale there are small scale farmers who have been given pieces of land and are without water and have to rely on the river water for their agricultural activities .

Table 23: Average consumption per household /day

Merafong	Westonaria	Mogale
25-501	25-501	2501

In Mogale daily average water consumption per household is 250L whilst for Merafong and Westonaria its 25-50L (Table 23).Water shortages occur in all the municipalities except for Westonaria. To augment the supplies in the households, for Mogale city they have boreholes draining the Zuuberkom dolomitic compartment. They also have reservoirs which are connected to the bulk water distribution network. In Merafong, they have Jojo tanks, which are storage tanks with a tap outlet, where the municipality refills with water for domestic use by the community. In the cases of serious shortages, the Merafong Municipality sends water trucks to the communities. The alternatives are mainly used for domestic purposes. In Westonaria, the municipality has set up communal water kiosks for the informal settlements which are found next to Donaldson Dam (Figure 1).

5.2.4 Mine survey

From the interview with the mining environmental representative of a Gold mine in Carletonville, it was noted that the main by-products of the gold extraction processes include uranium, mercury and cyanide and SO_x. The major environmental impacts are air, water and land pollution. This mine confirmed that they discharge process water into the WFS River, but they reuse and recycle it in their process before discharging. The mine also monitors the effluent within a 10km radius from the tailings dams and they do routine water quality tests monthly. As per the MMA they have a mine closure plan, where they have committed to rehabilitation and remediation of the environmental impacts arising from the gold extraction processes for example in terms of acid mine drainage, they have constructed wetlands, and they are working with geochemists towards the use of a special form of clay which traps heavy metals. The mine has formed a network with Non-governmental organizations and environmental activist groups in the area to provide a platform for them to coordinate programs towards building and cleaning up the environment.

5.2.3 Water quality monitoring

Table 24: Water quality monitoring initiatives

Municipality	Monitoring of water quality	Polluter Pays Principle	Discharge Permits	Municipal bye laws	Other
Merafong	√			√	Blue Drop
Westonaria	√		√	√	Blue Drop
Mogale	√	√	√	√	Blue Drop

Across all the municipalities in the scope of the study, there is monitoring of water quality, in rivers, and all the water sources (Table 24). The concept of the polluter pays principle (PPP), is only adopted in the Mogale municipality, because they enforce what they call an industrial levy , whereas in the other municipalities, they stated that since DWAF is in charge of all the water resources, they had no control of pollution in the public water ways (river courses).The Blue drop System measures and compares results of the perfomance of Water Services Authorities and Providers according to minimum standards stipulated in the assessment process.

Table 25: Water quality and compliance

Municipality	Water quality status	Compliance status
Merafong	Poor	Non compliance
Westonaria	Average	Average compliance
Mogale	Below average	Non compliance

In Mogale, there is non-compliance (Table 25) and this is attributed to uncontrolled and untreated run off from slimes dams, derelict sand dumps, waste rock dumps which end up in the WFS. Eroded slime material silt up wetlands and water courses. In Merafong, the same issue of mines discharging into water ways is also contributing to the non-compliance, abattoirs in the municipalities were also implicated as culprits, dumping waste into the WFS. Thus in municipalities like Westonaria and Mogale have implemented the programs like

Integrated Water Resources Management (IWRM) and Water Demand Management (WDM) (Table 26).

Table 26: Resources management programs in the WFS

Programs	MERAFONG	MOGALE	WESTONARIA
IWRM			√
WDM		√	√

5.2.4. Stakeholder participation

Stakeholders involved in the above mentioned programs (Table 24) especially the integrated water resources management include Department of Water affairs and Forestry, environmental activist groups, the Rand Water Board, Non-governmental organizations, government departments for example West Rand District Municipality(WRDM)and Gauteng Department of Agriculture and Rural Development (GDARD). In Mogale city, they raised the concern that the participation of stakeholders was minimal. The Merafong Municipality stated that they coordinated with mines to create programs of surface and ground water.

5.3. Water institution

The following section is a comprehensive discussion on the policies, statutes and government publications on water management in South Africa. In this discussion, focus is on the weaknesses and grey areas in the policies and their implementation and the consequences thereof to communities like the Wonderfonteinspruit.

5.3.1. Vulnerabilities in the Policies and implementation

Despite the redrafting of legislation on water, waste management, and mine, many of the changes have not been successfully implemented (Adler et al., 2007). Adler et al., (2007) stated that the reasons for non–implementation are the lack of specificity in the legislation and conflicts between the departments due to the duplication of responsibilities amongst other things. In agreement Godfrey, (2007) states that fragmentation and overlapping or vaguely defined roles and responsibilities regarding waste management are characteristic of the United States of America as well as South Africa. For example, mineral residue is not classified as waste and is considered a potential future source of minerals (Godfrey, 2007).In a study on the SADC region, assessing environmental sustainability in water resources management it was discovered that although water was utilized by many sectors the legislation was compartmentalized (Hirji and Ibrekk, 2001).This leads to the lack of coordination between the various sectors.

Furthermore, Hirji et al., 2002 noted that the lack of clear definition of environmental sustainability criteria for water management has led to limitations in integrating the criteria into the decision making process. For example it is ironic that mineral residues are not considered as waste. This is because according to statistics given out by DWAF 2001, which stated that South Africa produces waste mounting up to 533 million tons yearly, it was noted that 87.7% of this waste is actually mineral waste of which 47% comes from gold mining activities like those in the WFS catchment. The government should have prioritized mineral waste and residue in its policy framework and thus incorporated it in its NWRS.

Strydom (2007) indicated that despite waste management facilities in South Africa being internationally acclaimed, waste management is still currently afforded a low priority within all spheres of government, resulting in failing waste management services that negatively affect human health. For example, in a study on policy reform trends in 11 countries South Africa included (Saleth and Dinar 2000),it was noted that one of the best practices incorporated as a strategy in the Brazil institution is the prioritization of regions and sectors relative to their susceptibility to water quality and quantity problems (Saleth and Dinar 2000). In other words, for South Africa, the catchments facing the most serious problems of contamination are prioritized and the stakeholders are targeted to work with government in reducing or alleviating this issue.

In the case of the WFS catchment where there is generation of radionuclides and yet the Hazardous Substances and Articles Act does not encompass radioactive waste. The radionuclide contamination is reduced to a trivial issue yet radionuclides have significant environmental and public health implications (Busby and Schnug 2007; Raabe 2010; Stephen 2009). Government notably continues to be reactive in dealing with environmental issues. For example, in terms of water pollution, Adler et al., 2007, concluded by citing the Polluter Pays Principle adopted in the NWA and the carrying out of EIAs as prescribed by the NEMA whereby companies are supposed to pay for the contamination arising from their activities. However, there have been arguments as to whether this is effective (Komen, 2011, European Commission report 2009). Compared to the environmental costs in terms of contamination as well as rehabilitation, the fines are insignificant such many governments are looking for other forms of economic instruments like environmental taxes to contribute to the clean-up (Fullerton 2009).

In the NEM (WA), there is no emphasis on waste minimization initiatives but it allows uninhibited waste production and primarily focus on treatment and disposal of waste. This is due to the ignorance on the part of waste generators and shortcomings in the current legislative and regulatory framework. However, the attitude of industry is beginning to change, because waste management is now costly and there are regulations that are more stringent (De Bakker et al., 2005). The same cannot be said of local government, who are the custodians of the policies on the ground.

Despite the above-mentioned vulnerabilities in the policies, the water law in South Africa has been labelled as most comprehensive in the world (Schreiner &Van Koppen 2002). De Coning (2006) reaffirmed that there exists valuable experience in terms of water policy process in South Africa, although there are no clear-cut indicators to determine the effectiveness of the current institutions. Although the constitution and water principles and subsequently the NWA all emphasize the need for conservation of water quality and the mechanisms to determine trends and the status of water quality, there is still a lot to be done regarding water management at the grassroots level. CMAs for instance, despite several of them being established only two are fully functional that is, the Inkomati and Breede-Overberg agencies (Segal 2009). This leads to one question: are the institutions able to measure up in terms of implementation to the framework? The NEM (WA) currently has no follow up strategic plan for implementation purposes.

Walmsley et al., 2001 studied the indicators of sustainable catchment development and catchment management and they defined these indicators to be ideal means by which progress towards a goal (in this case integrated water resources management) can be monitored. Water quality trends is evidently one of the indicators that come amongst others such as ecosystem health, water use and availability, waste produced and the level of compliance. Since these indicators are directly reflective of the policies and administration they can be used to assess the effectiveness of the implementation of the water, waste and mine closure law in the WFS catchment.

5.3.2. *Inference to the study area*

Compared against the sustainable development indicators, the levels of mineral waste being produced in the catchment are evidently high (Winde 2012).More than 6 billion tons of tailings have been reported for the Witwatersrand basin ever since the commencement of gold mining activities (Janisch, 1986, Robb and Robb 1998a, b). Nevertheless, the level of compliance is very low and there is poor water quality since many points along the course of the WFS River have been found to exceed the maximum permissible limit for heavy metals and radionuclides (Winde, 2006; Coetzee, 2006).The ecosystem health in particular for inhabitants in this catchment is evidently at risk especially for informal settlements, which lack access to potable water (Marara, et.al 2011). Several health effects are documented arising from ingestion of drinking water contaminated with heavy metals and radionuclides, which are rife in this catchment.

In addition, the problem of water pollution from mine waste has not been prioritised in the government's mandate. The ISO 14001 environmental management system should be made mandatory for mining companies so that there is commitment on their part as well as identification and continuous monitoring and mitigation of environmental impacts.

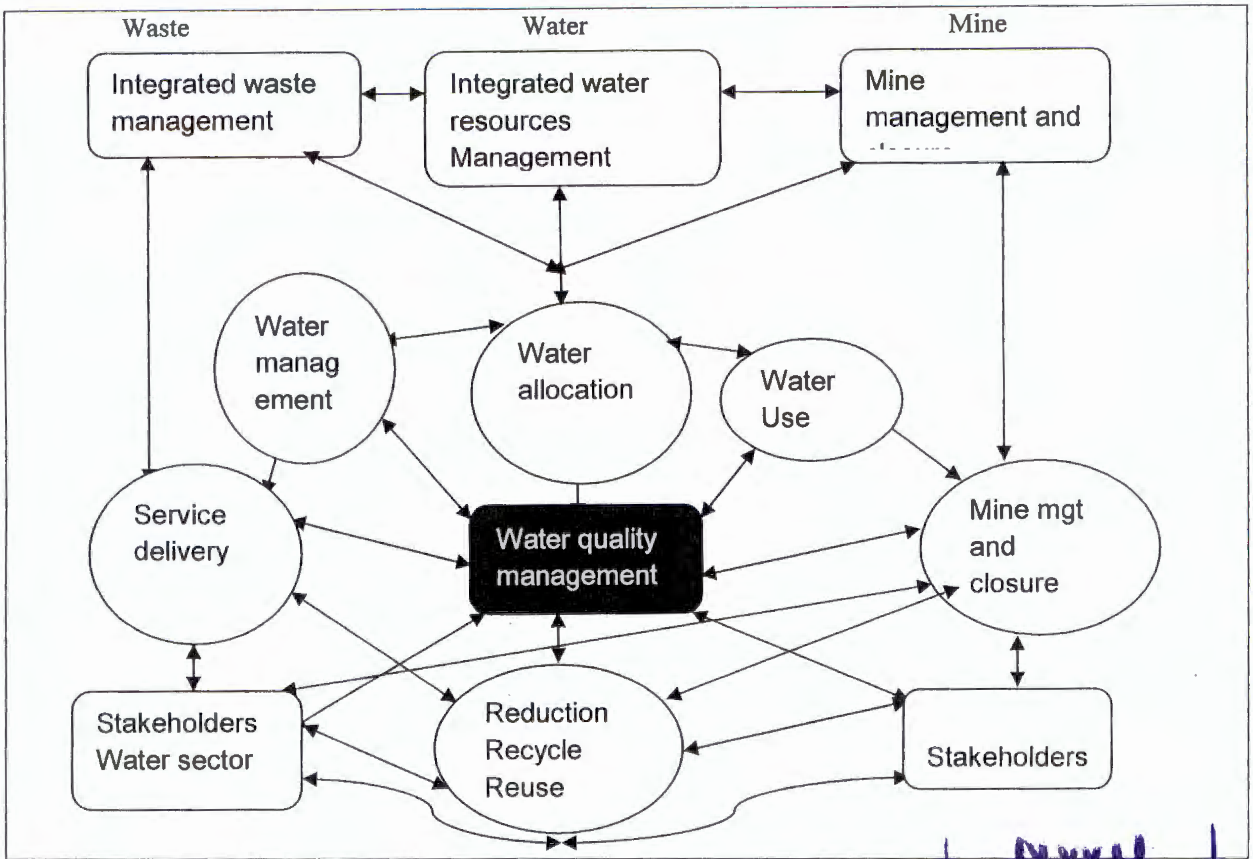

Figure 26: Intersectoral web

There is a need for policy makers in the waste, water and mining sectors to come together and work towards common ground which is water quality management and the alleviation of the problem in their different capacities.

Contemporary literature has many models which aim at explaining the water institution and the linkages within the institution thereof .Deriving from current literature and results of the review, a model was created (Figure 26) in an effort to portray the concept of the water institution not existing in isolation, this model proposes that in order to achieve the optimal implementation of the water institution there should be culture of inter collaboration between water and other related institutions.

The fact that this model is a web illustrates the interconnectedness of the various components with the water, mine and waste sectors. Symbiotic relationships can be identified, which can only be sustained if the three main sectors were working together as a unit. It can be derived that since the water sector does not exist in isolation, management of the water resources should be approached the in the same manner if the optimal goal of water resources is to be achieved .Thus the model calls for integration of the framework on water waste and mine management for instance a white paper on integrated water, waste and mine management. The success of optimal water resources management largely relies on a balance between the various sectors whereby, if there is any weakness along the web, the goal cannot be achieved.

Conclusion

It can be concluded that although the policies exist, the content and the implementation is not as effective, it is lagging as evident from the situation in the WFS catchment. It is clear that there is fragmentation between departments as well as duplication of roles, thus resulting in the poor implementation of the water institutions. There is a need for the clear-cut definition of roles and responsibilities at each level and for each sector. Public perceptions have a bearing on and are indicative of the extent to which the institutional set up for water resources in the catchment is being implemented. From the measures devised in the study, the suitability, effectiveness and disease awareness indices, it can be concluded that based on community perceptions the institutional set up for water resources management is not effective, there is need for the municipal authorities and other stakeholders to be proactive and to engage the community and also to devise educational programmes related to water quality management and health related issues.

CHAPTER 6

6. CONCLUSION AND RECOMMENDATIONS

This final chapter summarizes the main research findings study, by highlighting and giving an overview of the significant outcomes emanating from this research. Furthermore, it details the implications of these findings and thus provides suggestions and recommendations for future research to advance water quality provision for communities within mining areas.

6.1. Conclusion

The main water sources in the catchment are tap and river water. Findings revealed that there is significant use of river water from the WFS for domestic consumption, as either an alternative or a main water source. The informal settlements lack piped water systems as well as communal water outlets thus there is significant use of the WFS stream water for domestic consumption either as a main water source or as an alternative. The quality of water from the informal water sources is not in compliance with the SANS 241 and WHO 2011 for As and U and as such, informal settlements of Carletonville, Bekkersdal and Khutsong are at risk of serious health problems. Due to these problems of water shortages and poor water quality, communities have lost confidence in the local government, which might deter them from getting involved in water resources management programs. These findings not only provide a baseline for a long-term epidemiological survey to assess health impacts arising from mining activities in the catchment but also suggest policy implications in the area of water resources management, service delivery and waste management in particular the operational aspect of the water institution.

Although South African environmental institution in particular the water and other related institutions are perceived to be the best in the world, it is vulnerable because of its lack of clarity as well as duplication of responsibilities. In addition, policy implementation is lagging. It is clear that there is fragmentation between departments as well as duplication of roles at play, consequently, the poor implementation of the water institutions. There is a need for a clear definition of roles and responsibilities at each level and for each sector. The problem of water pollution from mine waste is clearly not a priority in the government's mandate. The ISO 14001 environmental management system should be made mandatory for mining companies so that there is commitment on their part as well as identification and continuous monitoring and mitigation of environmental impacts. Although the current situation in the catchment is because of the government's associative rather than regulatory role - a repetition of the prior government's mistakes is in order, because there is a continued reactive approach rather than a precautionary strategy by the current government.

6.2. Recommendations

The study has shown that the condition of water resources in the Wonderfonteinspruit catchment, South Africa, has been affected adversely by mining activities over the past century. The following recommendations are drawn.

- Supply of potable drinking water for the informal settlements in the WFS catchment should be improved.
- The Wonderfonteinspruit catchment municipalities should initiate and implement programs on environmental education to conscientize the communities on aspects regarding water resources management as well as environmental health, so as to enable these communities to participate, contribute and adopt a culture of proactiveness regarding environmental issues.
- There should be development of indicator guidelines for the water sector for the purposes of monitoring, self-evaluation and continuous improvement.
- A further inquiry into the health risks arising from the consumption of the water should be done in the form of a cohort study going back to determine the extent of damage that has emanated as a result of consuming the WFS waters.
- To achieve the optimal implementation of the water institution there should be culture of inter-collaboration between water and other related institutions. There is a need for policy makers in the waste, water and mining sectors to come together and work towards common ground which is water quality management and work towards the alleviation of the problem in their different capacities as illustrated in Figure 27.

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This questionnaire is administered in fulfilment of the Master of Science degree in Environmental science at the North West University, Mafikeng Campus, in a research on '**Radionuclide and heavy metal contamination of drinking water sources in Wonderfonteinspruit catchment, South Africa**'. The research is guided by the ethical principles of accountability, academic and scientific professionalism, transparency and respect and protection therefore all the information shall be treated as strictly confidential and will be used for the purpose of this research only.

Please tick where appropriate

SECTION ONE: PERSONAL DETAILS

1.1GENDER OF RESPONDENT

Male	Female
1	2

1.2 MARITAL STATUS

Single	Married	Widowed	Divorced	Other
1	2	3	4	5

1.3 AGE

16-25	26-35	36-45	46-55	56+
1	2	3	4	5

1.4POSITION OF RESPONDENT

Head of household	Wife	Child	Other(specify)
1	2	3	4

1.5LIVELIHOOD STRATEGY

Employed	Unemployed	Self -employed	Other
1	2	3	4

1.6HIGHEST EDUCATIONAL LEVEL ATTAINED

None	Grd1-7	Grd 8-12	Diploma	Degree	Postgrad	Other(specify)
1	2	3	4	5	6	7

1.7 RESIDENTIAL PERIOD

<1Year	1-3years	4-10years	11-20years	21-30years	+30years
1	2	3	4	5	6

SECTION TWO: WATER SOURCES AND USES

2.1What are your main water sources and uses?

Water sources	Water uses				
	Drinking	Cooking	Bathing	Laundry	Other
2.1.1 Tap	1	2	3	4	5
2.1.2 Borehole	1	2	3	4	5
2.1.3River/stream	1	2	3	4	5
2.1.4Other(specify)	1	2	3	4	5

2.2 Do you experience water shortages?

Yes	No
1	2

2.3 How frequently do you experience water shortages?

Never	Daily	Weekly	Monthly	Yearly	Other (specify)
1	2	3	4	5	6

2.4What are the alternative water sources during water shortages?

Alternative water sources	Water uses				
	Drinking	Cooking	Bathing	Laundry	Other(Specify)
1.Bowsers	1	2	3	4	5
2.Wells	1	2	3	4	5
3.Stream /river	1	2	3	4	5
4.Boreholes	1	2	3	4	5
5.Bottled Mineral	1	2	3	4	5
6.None	1	2	3	4	5
7.Other	1	2	3	4	5

SECTION THREE:WATER QUALITY AND COMMUNITY PERCEPTIONS

3.1 Do you have any problems related to water quality?

Yes	No
1	2

3.2 Do you think water from all the water sources in the area is suitable for?

	Yes	No
Drinking	1	2
Cooking	1	2
Laundry	1	2
Bathing	1	2
Other (specify)	1	2

3.3 Give reasons for your response in question 3.2 above

....

....

…………………………………………………………………………………………………
……………
3.4 What steps do you take to pretreat water before use for?

Water use	Pretreatment method				
	Boil	Filter	Use a cloth	Settling	Other (specify)
Drinking	1	2	3	4	5
Cooking	1	2	3	4	5
Other	1	2	3	4	5

3.5What is the municipality doing to provide you with adequate potable water?

Nothing	Boreholes	Protected wells	Bowsers	Other(specify)
1	2	3	4	5

3.6Do you think that the Municipality's efforts to provide adequate potable water are;

i) Effective?

Yes	No
1	2

ii)Sufficient?

Yes	No
1	2

3.7Explain…………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
……………

3.8What have you done as a community to ensure that there is provision of adequate potable water?

Nothing	1
Reported to the chief	2
Formed a water committee	3
Reported to the municipality	4
Other (specify)	5

SECTION FOUR: HEALTH AND AWARENESS

4.1Do you think that water quality is important?

Yes	No
1	2

4.2 Poor water quality causes…..

Cholera	1
Diarrhoea	2

Skin cancer	3
Kidney damage	4
Lung cancer	5
Bladder problems	6
Other (specify)	7
Don't know	8

4.3 Which of the following are the three most serious diseases in your area?

Cholera	1
Diarrhoea	2
Skin cancer	3
Kidney damage	4
Lung cancer	5
Bladder problems	6
Other (specify)	7
Don't know	8

4.4 Which of the following diseases/conditions listed below have you ever suffered from?

Pigmentation changes	1
Skin cancer/Rushes	2
Kidney problems	3
Lung problems	4
Bladder problems	5
Other (specify)	6
None of the above	7

4.5 Do you receive any health education related to water quality?

Yes	No
1	2

4.6 How often do you receive health education?

Daily	Monthly	Weekly	Yearly	Other (specify)	Never
1	2	3	4	5	6

4.7 What sort of messages do you get?

Boil	Unclean water causes	Add jik	Water from WFS is dirty	Other (Specify)	None
1	2	3	4	5	6

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Please tick where appropriate

Section one water sources and uses

1. Which of the following are the main sources of water supply for this Municipality?

Rivers	Dams	Boreholes	Wells	Other (specify)
1	2	3	4	5

2. Specify on the types of water use for every source.

Water sources	Water uses				
	Drinking	Cooking	Bathing	Laundry	Other (Specify)
River	1	2	3	4	5
Dams	1	2	3	4	5
Borehole	1	2	3	4	5
Wells	1	2	3	4	5
Other (Specify)	1	2	3	4	5

3. What is the average consumption per household per day?

<25L	25-50L	51-75L	76-100L	>100
1	2	3	4	5

4. Do you experience water shortages?

Yes	No
1	2

5. Does the municipality augment with alternative supplies ?

Yes	No
1	2

→ **If No go to question 8**

6. What alternatives does the municipality provide to residents?

None	Bowsers	Boreholes	Wells	Other (specify)
1	2	3	4	5

7. Specify on the types of water use for the alternative sources?

Alternative water sources	Water uses				
	Drinking	Cooking	Bathing	Laundry	Other(specify)
Bowsers	1	2	3	4	5
Wells	1	2	3	4	5
Boreholes	1	2	3	4	5
Other	1	2	3	4	5

8. It is every municipality's mandate to provide adequate potable water to all its residents ,what mechanisms have been put in place to achieve this ?

Drilling of boreholes	1
Provision of water kiosks	2
Protected wells	3
Bowsers	4
Nothing	5
Other (Specify)	6

9. How far has the municipality gone in ensuring potable water supply to the **informal settlements**?

Drilling of boreholes	1
Provision of water kiosks	2
Protected wells	3
Bowsers	4
Nothing	5
Other (Specify)	6

SECTION TWO : WATER INSTITUTION AND COMPLIANCE

10. What are the measures in place to ensure water quality for all the water sources in the municipality?

Monitoring of water quality	1
Polluter pays principle	2
Discharge permits	3
Other(specify)	4

11. Is there monitoring of effluent discharges into public water ways and rivers ?

Yes	No
1	2

12. What is the status quo of water quality in the rivers in this area?

Poor	Below average	Average	Good	Excellent
1	2	3	4	5

13. Does the municipality have bye-laws regulating effluent discharges into water sources?

Yes	No
1	2

→IF No go to question 16

14. How do you rate compliance in general by Mining companies?

Non compliance	Average	Excellent
1	2	3

14.1Explain

....

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15. Has the Municipality implemented an IWRM (Intergrated Water Resources Management)?

Yes	No
1	2

16. If yes in question 15, what steps has the municipality taken in involving stakeholders' participation in water resources management?

....
....
....

17. Which stakeholders are involved?

Mines	1
Industries	2
Health	3
NGOs	4
Other (specify)	5

18. Has the municipality implemented a Water Demand Management (WDM)

Yes	No
1	2

THANK YOU

This questionnaire is administered in fulfilment of the Master of Science degree in Environmental science at the North West University, Mafikeng Campus, in a research on **'Radionuclide and heavy metal contamination of drinking water sources in Wonderfonteinspruit catchment, South Africa'**. The research is guided by the ethical principles of accountability, academic and scientific professionalism, transparency and respect and protection therefore all the information shall be treated as strictly confidential and will be used for the purpose of this research only.

Please tick where appropriate

1. Which of the following categories of mining does your activities fall under?

Mineral extraction	Mineral processing	Other (specify)
1	2	3

2. What minerals are
3. Which of the following are extracted /processed?

Uranium	Gold	Platinum	Other(Specify)
1	2	3	4

4. the major products and bye-products from the process?

Element	Product	Bye product
Uranium	1	2
Gold	1	2
Cyanide	1	2
Mercury	1	2
Radium	1	2
SO_2	1	2
None	1	2
Other (Specify)	1	2

5. What are the major environmental impacts arising from the mining activities?

Air pollution	1
Land degradation	2
Acidic mine drainage	3
Water pollution	4
Loss of biodiversity	5
Other (specify)	6

6. Do you discharge off any effluent?

Yes	No
1	2

→ **If No go to question 7**

7. If No in 5, how do you deal with the effluent?

Recover	Recycle	Reuse	Other (specify)
1	2	3	4

8. Where do you discharge the effluent?

River	1
Dam	2
Pond	3
Other	4

9. Do you have a permit to discharge?

Yes	No
1	2

10. If yes, what is the colour code on your permit?

Blue	Green	Yellow	Orange	Red
1	2	3	4	5

11. Are there any measures to ensure that the effluent does not come into contact with fresh water resources?

Yes	No
1	2

Explain your Answer above

....

....

....

12. Do you monitor the water sources which are in close proximity to the mines slimes dams ?

Yes	No
1	2

→**If yes go to Question 12**

If No, give a reason, then, →**go to Question 15**

....

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13. Within which radius from the point of discharge do you monitor the water quality?

5km	10km	15km	+15km	Other specify
1	2	3	4	5

14. How many monitoring points are there?

1-10	11-20	21-30	+30	Don't know
1	2	3	4	5

15. How frequently do you monitor and record the data?

Daily	Weekly	Monthly	Annually	Other (Specify)
1	2	3	4	5

16. Which of the following guidelines do you use?

DWAF	1
WHO	2
Municipal Bye Laws	3
Other (specify)	4

17. Compared against the following guidelines which one are you compliant?

Guideline	Compliant	Non-compliant	Don't know
DWAF	1		
WHO	2		
Municipal Bye Laws	3		
Other (specify)	4		

18. Do you have a mine closure plan?

Yes	No
1	2

If No, why? →go to question 19

....

19. If Yes, how do you intend to deal with AMD when you close?

Neutralization of AMD	1
Leaching of tailings	2
Removal of Uranium	3
Use of fly Ash	4
Constructed Wetlands	5
Other (Specify)	6

20. Are there any programs in place to monitor and conserve water resources for the safety of the communities surrounding?

Yes	No
1	2

21. If yes, is the Community involved?

Yes	No
1	2

22. Explain the programs and community involvement?

....

....

....

23. Are you ISO 14001 accredited?

Yes	No
1	2

THANK YOU FOR YOUR TIME

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
MAFIKENG CAMPUS

Private Bag X2046, Mmabatho
South Africa, 2735

Tel: (018) 389-2311
Fax: (018) 392-5775
Web: http://www.nwu.ac.za

The Municipal Manager,
Westonaria Local Municipality,
P.O. Box 19,
Westonaria,
1780

Dear Sir/Madam

Re: NOTIFICATION LETTER TO OBTAIN DATA FOR RESEARCH

Tafadzwa Marara is a Masters student, under the supervision of Dr. L. G. Palamuleni and Prof. E. Ebenso, at the North West University (Mafikeng campus) in the School of Environmental and Health Sciences. Tafadzwa is currently working on "Radionuclide and heavy metal contamination of drinking water sources in Wonderfonteinspruit catchment, South Africa."

Critical to this research work is the primary and secondary data from your office and some interviews with residents in Bekkersdale Township to identify drinking water sources and determine the presence of radionuclides and heavy metal concentration in the sources. We are aware of the sensitivity of the project she is doing and as such all measures pertaining to the confidentiality of the report and outcome are well defined under the current policy of ethical considerations [illegible] University. Be kindly informed that the research that Tafadzwa is conducting is solely for academic purposes.

Any assistance rendered to her will be greatly appreciated.

Yours Sincerely,

Prof. T. A. Kabanda
Head of Department
Geography and Environmental Sciences

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT
MAFIKENG CAMPUS
OFFICIAL
2010 -10- 20
Tel: 018 389 2344/2174 Fax: 018 389 2377/2052
SCHOOL OF ENVIRONMENTAL & HEALTH SCIENCES
DIRECTOR'S OFFICE

Local Municipality

Cnr Saturn & Neptune Street, Westonaria 1780
19, Westonaria 1780
(011) 278-3020, (011) 753-2516
E-mail: mlethetsa@westonaria.gov.za
www.westonaria.gov.za

Our Ref/Ons Verw./Inamba Yethu
Your Ref/U Verw./Inamba Yakho
Enquries/Navrae/Imibuzo G Viljoen

9 November 2010

Prof TA Kabanda
Head of Department
Geography and Environmental Science
North West University
Private Bag X2046
MMABATHO
2735

Sir/Madam

NOTIFICATION LETTER TO OBTAIN DATA FOR RESEARCH: MS. TAFADZWA MARARA

Your letter dated 20 October 2010 regarding the above matter, refers.

Westonaria Local Municipality has no objection to the proposed academic research work to be done by your student, Ms. T. Marara in pursuit of her studies as indicated in the attached letter.

It would be appreciated if she could furnish the Council with a written programme (periods and areas to be visited for data collection) in order for Council to inform the relevant Ward Councillors of her research.

We certainly hope that Ms. Marara's research will also be to the benefit of all communities in Westonaria and we wish her success in her studies.

Regards,

TN NDLOVU
ACTING MUNICIPAL MANAGER

(Ms Morolo/Letters/2010/Notification letter to obtain data for research)

Appendix 6

Table 27: Independent t test seasonally variations for Arsenic

		t-test for Equality of Means						
		t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
Arsenic	Equal variances assumed	.084	22	.934	.21058	2.49933	-4.97271	5.39388
	Equal variances not assumed	.084	21.967	.934	.21058	2.49933	-4.97317	5.39434

Table 28: Independent t test seasonally variations for U^{238}

		t-test for Equality of Means						
		t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
URANIUM 238	Equal variances assumed	6.082	22	.000	39.46751	6.48934	26.00944	52.92557
	Equal variances not assumed	6.082	11.000	.000	39.46751	6.48934	25.18458	53.75043

Table 29: Independent t test seasonally variations for U^{235}

		t-test for Equality of Means						
		t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of t Difference	
							Lower	Upper
URANIUM 235	Equal variances assumed	-1.019	22	.319	-10.02075	9.83552	-30.41837	10.37687
	Equal variances not assumed	-1.019	20.665	.320	-10.02075	9.83552	-30.49504	10.45354