FACULTY OF HEALTH AND APPLIED SCIENCES

ASSESSMENT OF THE EFFECT OF GROUNDWATER QUALITY ON HUMAN HEALTH IN OVITOTO, OTJOZONDJUPA REGION, NAMIBIA

BY

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Thesis submitted in fulfilment of the requirements for the award of Master of Health Sciences degree in the Department of Health Sciences, Faculty of Health, Applied Sciences and Natural Resource Sciences

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April 2022

Abstract

Water is an essential part to the well-being and economic development of mankind. Namibia's dry climate makes it susceptible to drought; hence, water is a scarce resource. To address water scarcity, boreholes are drilled to access groundwater for agricultural, industrial and domestic use. Many local authorities rely on this resource for supply to residents for domestic and other uses. But, the quality of groundwater is influenced by various factors, including pollution from point and non-point sources. A case study was done which involved the collection of water samples in the boreholes and laboratory analysis and assessment of the quality of sampled water. Non-probability-purposive sampling method was applied in the selection of sampling site. This study assessed the physicochemical (toxic heavy metals such as zinc (Zn), copper (Cu), cadmium (Cd), iron (Fe), manganese (Mn) and lead (Pb) as well as microbiological (Coliforms, *E. coli* and heterotrophic plate count) water quality of groundwater from boreholes that are supplied to the community of Ovitoto in Otjozondjupa region. This was done to assess the prevalence and possible human health concern as an outcome of consumption of the water. A total of 108 water samples were collected over a period of six months at an average of monthly intervals. Elemental components were extracted from water samples using mineral acid digestion and analysed through the use of Inductively Couple-Plasma Emission Spectroscopy (ICP-OES), while the microbial entities were analysed using the Polymerase Chain Reaction method (PCR). The overall mean concentration of heavy metals in the absorbed water samples through the sampling periods were Zn (0.83 mg/kg), Cd (0.01 mg/kg), Pd (0.02 mg/kg), Fe (17.76 mg/kg) and Mn (7.09 mg/kg). A strong correlation (r=0.99) was obtained between Zn and Cd while Cd and Cu were averagely correlated (r=0.55). Target Hazard Quotient (THQ) values < 1 was recorded for all analysed heavy metals, both in children and adults were below the permissible limits. However, Carcinogenic Risk Index (CRI) values for Mn was > 1 for both adults (4.75) and children (18.10). There is the possibility of carcinogenic health risk by Zn with a value of 0.13. Of great concern, however, is the potential development of carcinogenic health risk with respect to Mn. Other metals do not have physical benefits to human system, and they are toxic at low levels. Therefore, proper monitoring and quality assurance protocol of the level of toxicity of heavy metals in borehole water is recommended.

Keywords: Groundwater, Health Risk, Heavy metals, Microbial, Ovitoto, Namibia

Attestation

I, Priskila Shevamwaveke Mwatukange, hereby declare that the work contained in this thesis is my original work. I further declare that other people's work used was acknowledged through referencing.

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Acknowledgments

First and foremost, I give praise and thanks to the Almighty God for his grace and guidance throughout the development of the proposal and successful completion of the research project.

I would like to express my appreciation and sincere gratitude to my research supervisors, Prof. Omotayo Awofolu and Mr Immanuel Zeriapi, for their contributions towards the completion of this research project. Despite their busy schedules, they took time to listen, guide and keep me going. Their dynamism, vision, sincerity, and motivation have deeply inspired me.

This work would not have been possible without the financial support (bursary) from Namibia Chamber of Environment. I am especially indebted to Dr Chris Brown, the chairperson of the Chamber bursary steering committee and the team for funding my studies.

My gratitude goes out to Mrs Conradie, the Head of Quality Assurance and Laboratory Services at NamWater, for giving me access to their laboratory facilities where the experimental process was conducted. My gratitude also goes to Mr Riukua Hukura, the Ovitoto constituency councillor and Mr Tjandero Assaph Tjituka, the school principal at Oruuwa Primary School and the entire staff for their support during data collection period.

I would also like to thank my family for their continuous support and encouragement throughout this research.

Finally, I would like to thank my classmates for their motivation and positive criticism during my studies.

List of abbreviations

AS	Arsenic
AT	Average Timing
AWWA	American Water Works Association
Ca	Calcium
$CaCO_3$	Calcium Carbonate
Cd	Cadmium
CFU	Colony Forming Units
Cl	Chlorine
Cr	Chromium
CRI	Carcinogenic Health Risk Index
DO	Dissolved Oxygen
EC	Electrical Conductivity
ED	Exposure Duration
EDI	Estimated Daily Intake
EFD	Estimated Frequency Dose
Fe	Iron
HHRA	Human Health Risk Assessment
HHRAE	Human Health Risk Assessment Equation
HI	Hazard Index
HQ	Hazard Quotient
IR	Ingestion Rate
IWRM	Integrated Water Resource Management
K	Potassium
KP	Dermal Permeability Coefficient
Pb	Lead
LWPC	Local Water Point Committee
Mg	Magnesium
Hg	Mercury
Na	Sodium
NamWater	Namibian Water Corporation
NDWQS	Namibian Drinking Water Quality Standards
Ni	Nickel
NSA	Namibia Statistic Agency
NTU	Nephelometric Turbidity Units
PCA	Plate Count Agar
pH	Hydrogen ion Concentration
RFD	Reference Dose
ESA	Exposed Surface Area
SAWQG	South African Water Quality Guidelines
Se	Selenium
SOER	State of the Environment Report
TBA	Tryptone Bile Agar
TDS	Total Dissolved Solids
THQ	Targeted Hazard Quotient
TP	Total Phosphorus
TSS	Total Suspended Solid
UN	United Nations
UNEP	United Nation Environmental Programme
USEPA	United States Environmental Protection Agency
WASP	Water and Sanitation Policy
WHO	World Health Organisation

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CHAPTER 1: INTRODUCTION

1.1. Introduction

Water is a crucial part to the well-being and economic development of mankind. Globally, groundwater signifies the world's largest and most valuable source of drinking water (Hoekstra & Hung, 2005). Yet, WHO (2014), projected that approximately 1.1 billion people worldwide are unable to access safe portable water. This situation has caused different institutions to make efforts in the provision of quality and portable water (Kubi, 2013). According to Karikariand et al. (2007), socio-economic and health status of many nations has been used as indicators in the development of water resources. Amalraj & Pius (2018), state that groundwater provides drinking water daily to an estimated 1.1 billion people globally and has signifies to be the most dependable resource for meeting rural water plea in sub-Saharan African due to governments' failure to meet the ever-increasing water needs, most people in rural areas depend on groundwater sources through boreholes as a substitute water sources. Hence, humans get groundwater through a borehole, which is drilled into the aquifer for domestic, industrial, agricultural use. But groundwater resources are also prone to pollution, which may reduce their quality.

Water is one of the resources that impact many aspects of the economy or of human and environmental health (Tavera, 2000). For this fact, one would expect people to have the greatest respect for the resource and protect and maintain its cleanliness. However, throughout the world, people are curiously indifferent and careless in this matter.

Based on the global development agenda, water has been accorded great significance. At the World Summit on Sustainable Development conducted at Johannesburg in 2002, countries were tasked to emulate Integrated Water Resource Management (IWRM) and water efficiency plans to assist the existing development in water resources deprivation and to achieve integrated land and water management and living resources while empowering national capacities (Sharip & Jusoh, 2010). The Agenda 21 made recommendations and provision of principles covering the water resources management in general- including provision of water, demand regulation, supply, and tariffs. Thus, management of water resources cannot be achieved fully without paying due consideration to water quality aspects.

The dry climate condition of Namibia made it vulnerable to drought, which means there is scarcity of fresh-water resources. To address water scarcity in the north-west of Otjozondjupa region, boreholes are being drilled to combat water scarcity in the settlement for agricultural, industrial, and domestic use. However, there is growing concern about the groundwater's quality in this locality. The concern was echoed by some members of the community and the councillor of the constituency. Preliminary inspection of piped water systems in the area revealed blockage due to massive deposit of powdery substance suspected to be Ca/$MgCO_3$, the compound responsible for water hardness.

In addition, the geological formation of the area may influence the water quality as well as seepage of chemical pollutants through the soil, emanating from diffuse and non-diffuse sources. UNEP (2010) stated that groundwater quality has been reported to be threatened by pollution from various activities such as mining and dumping sites. From the observation above, it becomes essential to assess the quality of the groundwater being consumed by people in this locality as a result of the health implications.

1.2. Problem statement

According to UNEP (2010), even though management technologies and new assessment have been done and policies implemented problems of water degradation and pollution continue. The term 'groundwater' is normally referred to as subsurface water that arises below the water table that is normally saturated. The quality of groundwater differs from place to place, depending on the types of soils, rocks, seasonal changes, and surfaces through which it moves (Trivede, Bajpai & Thareja, 2010). As it runs through the dregs, metals such as manganese and iron are melted and may later be found in high concentrations in the water (Moyo, 2013).

In Africa, surface water is the major source of water supply. Groundwater is widely used predominantly in arid and rural areas with only about half of the country's underground water resources being used (Moyo, 2013). Due to Namibia's high evaporation rates, unpredictable rainfall, and low conversion of rainfall to runoff, Namibia is a drought prone country, where water need outstrips available supply (Shuuya, 2009). This, together with growing water consumption, is putting great needs on the nation's current water sources. Potential contamination of groundwater in Namibia is quite high through seepages of chemical and pathogenic wastes especially in rural areas where pit latrines sanitary practices are common.

The study of Hoekstra and Hung (2013), indicates that human activities such mining and dumpsites can change the natural composition of groundwater via the deposition of microbial and chemicals substance directly on soils or land surfaces. Groundwater in mining areas is prone to heavy metal pollution, such as mercury, as mining acids are released into the atmosphere, which may later end up into the water (Abdurrahman & Abu-Rukah, 2006). In Otjozondjupa region, where mining activities occur, this may pose a great danger on the groundwater's quality (Nkwud, Theophine & Okogwu, 2019). Ovitoto is one of several settlements in Otjozondjupa region whose residents depend on groundwater for domestic and agricultural use.

The value of water from boreholes in terms of quality it is not constant, but usually it might comprise great amounts of nitrates – and this is an actual problem. High levels of hardness, microbiological problems and salinity have also been recorded in groundwater. Water quality difficulties have relatively been linked with insufficient sanitation (Moyo, 2013).

The WHO projected poor sanitation and unsafe water to cause 80% of all diseases in the emerging countries (Miller, 2000). Microbial pollution and metallic contaminants are severe distresses in many water institutions around the world (UNEP, 2006). The main problem in the study area is poor potable water supply due to mining activities, dumpsites, and lack of awareness amongst community members on water preservation. The maintenance of boreholes in Ovitoto areas was still limited largely due to insufficient financial allocation. Consequently, the water being taken from borehole reaching was unclean and polluted (Soer & Reneman, 2001). The provision of portable drinking water donates significantly to the reduction of waterborne diseases, and it improves people's living conditions, but poor water quality is detrimental to human health. World Health Organisation projected that 20% of the estimated 110 000 Namibians infected with waterborne diseases is found in Otjozondjupa region. Lack of adequate sanitary facilities and potable water are generally attributed to the spread of diseases (WHO, 2006).

Water contains naturally occurring physio-chemical contaminants that arise due to human-made activities such as dumpsites, agriculture, and mining. If these contaminants are not kept at acceptable levels, they may become detrimental to human health (Santos, Oliveira, Alves & Madeira, 2014). The Ministry of Environment and Tourism (n.d) noted that there is non-existence of data on water quality, and there is need to appraise the water quality database by making sure that routine sampling for water quality on the ephemeral and perennial rivers as well as dams.

All the above-mentioned activities have the possibility to negatively impact the quality of groundwater and human health; hence, it is vital that water is managed in such a way that its quality is preserved. The ways to sustainable water resources is to ensure the water resources quality is suitable for its intended uses. In addition, water conservation practices such as minimising water losses and water use efficiency should be substantially encouraged. Thus, groundwater quality testing and monitoring is of supreme importance in developing and developed countries (Singh, 2014). Previous studies give a clear picture of what different researchers have done pertaining to groundwater quality monitoring and human health risk assessment. Most studies focused on physicochemical and microbial groundwater quality analysis, and only few studies focus on the human health risks assessment of groundwater (borehole).

1.3. Background of the study area

Otjozondjupa region is located in the central region of Namibia. It has a total population of about 143 000 residents, and its capital is Otjiwarongo (NSA, 2013). Otjozondjupa region is distinguished for being the mass of the cattle farming activities and Waterberg Plateau Park. It is largely semi-arid, with rainfall ranging from 300-600 mm, increasing from the south-west to the north-east. The region’s agricultural activities are mainly livestock and crop farming. Surface water resources are scarce, and a majority of the community members depend on groundwater resources.

Ovitoto is a settlement, mainly occupied by OvaHerero people. It is located about 45 kilometres south-east of Okahandja, which, in turn, is positioned about 70 kilometres north of Windhoek. It covers an area of about 627 km^2 and all together contains of 19 villages. The villages that were part of the study are as follows: Okasogua, Okomakuara, Okandjiira, Ondamekondo, Okamuina, Ondamekondo 2, Oruuwa 1, Oruuwa 2 and Otjongombe.

The Local Water Point Committee (LWPC) in each villages managed the boreholes and oversees the payment and maintenance pertaining to the water points in the village. Though, poor managements and misuse impede the water flow, thus making water supply an extremely asymmetrical natural resource (South-West African Directorate of Water Affairs, 1979). In Otjozondjupa region, where mining activities occur, this may pose a negative impact on the quality of groundwater (Nkwud, Theophine & Okogwu, 2019). Ovitoto is one of several settlements in Otjozondjupa region whose residents depend on groundwater for agricultural and domestic. The total population of Ovitoto, the site of the study, is estimated to be around 6 000 (NSA, 2011). The settlement consists of farmers who depend heavily on agriculture and livestock farming.

A) Geology

Otjozondjupa region is a host to the world's largest meteorite, known as the Hoba meteorite. The area is portion of the Kalahari geological system, while the Aha Hills on the border with Botswana lessen the westward transference of wind-blown Kalahari sands into the NyaeNyae area. One of the most vital natural landscapes in NyaeNyae area is the system of Calcrete pans that are oftened filled with surface water during the rainy season, providing periodic access to water for livestock, people and wildlife (Lisao & Geldenhuys, 2017).

B) Climate

The climate condition of the area varies from arid to semi-arid, with a yearly rainfall of about 470 mm – while there is a high degree of inconsistency, and the area is prone to annual droughts, making it peripheral for rain-fed crop production. The average c day-to-day temperature is 33° Celsius, while overnight temperatures in winter can reach below freezing point (Lisao & Geldenhuys, 2017). The latitude and longitude of the area stand at 21. 9667◦S and 17.2167◦E.

C) Boreholes

Aquifers are drilled into the underground to extract water intended for agricultural and domestic use. There are about ten (10) villages in Ovitoto settlement. In each village, there are is at least one functional borehole to supply community members with water. Community members are selected as part of the committee to manage the pumping of those boreholes. Ovitoto is one of the settlements in Otjozondjupa region that depends largely on groundwater resource for domestic, agricultural and animal uses.

D) Economic activities

Agriculture and mining are the predominant economic activities that take place in the area. A majority of Ovitoto residents depend on animal farming for survival. Thus, for their animals to survive, provision of borehole water is made - even though Ovitoto is one the areas classified as arid. Zinc and manganese are being mined at Otozondu, an area near Ovitoto settlement. Smoke and dust being emitted from mines might end up in groundwater resources and contaminate them, thereby posing potential to negatively impact the quality of groundwater when poorly managed.

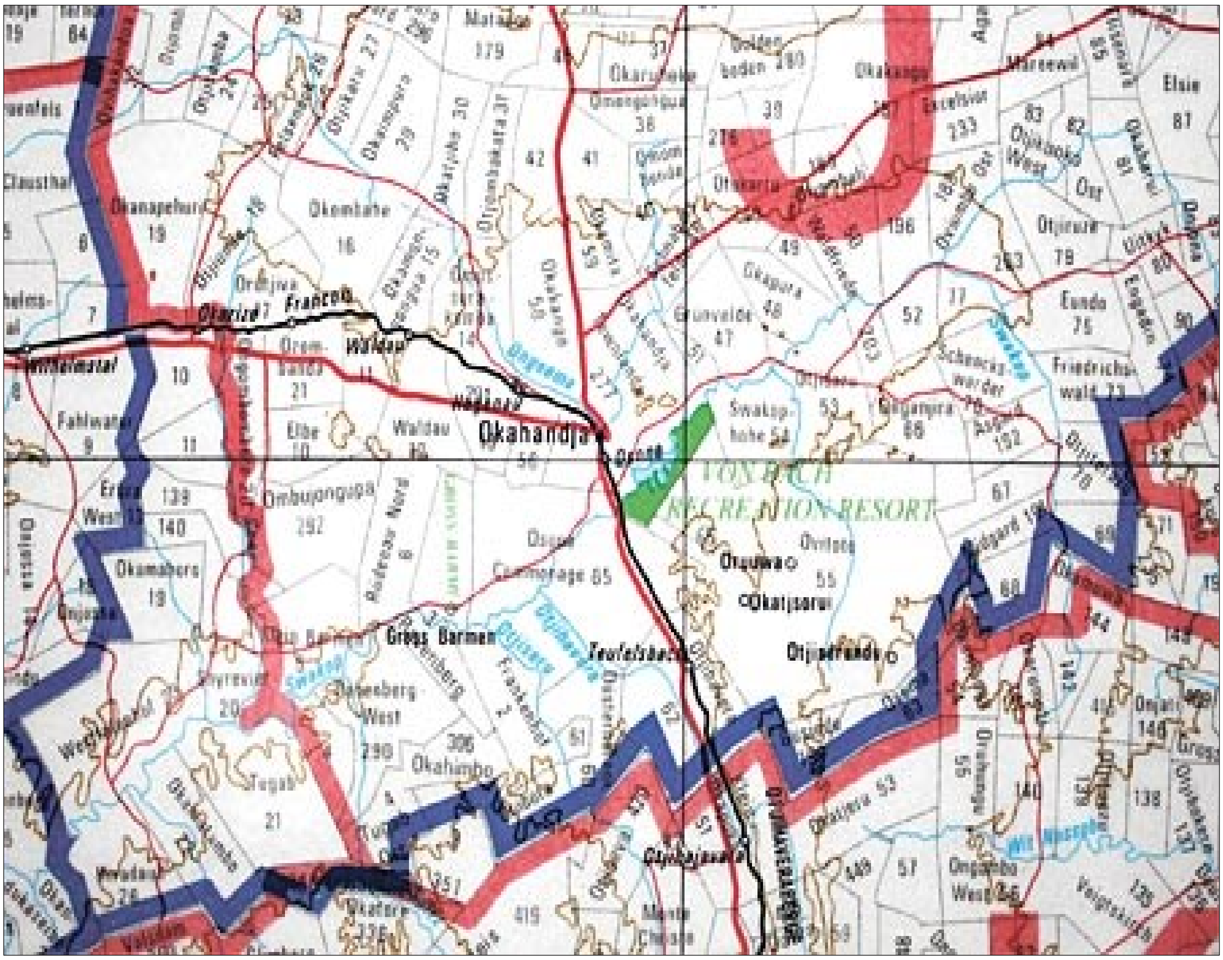


Figure 1: *Ovitoto area (Rosengreen, 2011)*

1.4. Possible contributing factors to groundwater pollution

Contaminants such as microbes, heavy metals and chemicals from waste materials are potential factors that can contribute to the pollution of groundwater. This is due to possible seepage or leaching of contaminated wastewater into the ground. One of the possible contributing factors to poor groundwater quality in the site of study is illegal dumping of waste near boreholes or improper handling and dumping of wastes near water points. This act is common in areas of low social economic status, where inhabitants do not have proper waste disposal facilities in place.

Another possible contributing factor could be negative attitude or lack of awareness on good hygiene practices in terms of water preservation among the community members. Considering that the majority of the population are involved in agricultural activities, they are not equipped with awareness on how to best preserve or the means to purify water. About 95% of the Ovitoto residents depend on borehole water; livestock is perceived to account for 80% of all water need in Ovitoto. This demand is met by the rainwater.

The insufficiency of sanitary facilities can also be a contributing factor towards groundwater pollution. 83% of households in the Ovitoto community do not have sanitary facilities (NSA, 2002), posing the risk of contamination of the borehole water by pathogens from human wastes. Moreover, the boreholes are subjected to dirty from human and animal faecal remains as well as solid wastes, mostly from household and farming runoff because during the rainy season, flood water from the vast drainage system washes into the borehole, bearing a potential health risk when consumed. Water contaminated with faecal remains being passed or washed into stream, river, or pool when it seeps into underground water can be linked to serious ill-health (Cheesbrough, 2006).

Other activities such as agricultural practices and mining can also be contributing factors towards groundwater pollution. Inorganic fertilisers and pesticides used in agricultural farming might end up in groundwater pollution through the process of leaching over a period of time. These are chemical compounds that can seriously affect human health. Furthermore, mining activities release harmful chemicals into the atmosphere that end up in the aquatic system when not managed properly. Such dusts or fumes may comprise heavy metals such as mercury, which is detrimental to human health when consumed.

1.5. Current intervention

The government of the republic of Namibia has taken necessary steps to advance water quality by generating policies that are attentive on regulation of the use of water resources, including groundwater. In view of this point, the Water and Sanitation Policy (WASP), which was endorsed in 1993, is an example of such policy. Ever since the establishment of WASP, water provision in rural areas has improved substantially to meet the livestock and domestic use requirement of most of the farming population. This progress has led to a high positive effect because 72% of Namibia's water is used for agriculture (Meier & Ankeny, 2017). The Namibian government also launched the Integrated Water Resource Management Plan for Namibia (IWRM) (2010) that aims to eliminate water scarcity through the alleviation of water pollution to make clean water resources available to all Namibians.

The Namibian people have adopted technology and innovation to make advancement in refining water quality and its availability in the country despite many environmental and geographic challenges (Meier & Ankeny, 2017). The Water Resources Management Act No. 11 of 2013 provides "the management, protection, development, use and conservation of water resources by prescribing water quality standards with regards to water, which is supplied for domestic purposes". Generally, however it can be said that the Namibian government has not paid sufficient attention to groundwater quality monitoring and testing. Physical examination of groundwater supply network at some residences and offices within the site of the study by the research team) revealed the presence of whitish powdery substance, suspected to be $CaCO_3$. This indicates that the water is most probably hard. In addition, possible contamination of groundwater, as a result of seepages of wastewater emanating from waste materials and agricultural wastes such as pesticides, justified the need to assess the quality of groundwater consumed by people at the site of the study.

1.6. The benefit of the study

Surface and groundwater pollution through inappropriate management of wastes and pollution from human-made activities such as agriculture, mining and deposition of human and animal wastes directly into the water resources are the mainly sources of water pollution in Namibia (Anonymous, 2001). This is applicable especially to peri-urban areas, and other areas that have developed but are without appropriate sanitation services and water supply system. Water contamination donates to the scarcity of this resource, as the water may be contaminated to stages where it is becomes costly to treat.

The results of the study provided information on groundwater quality from the site of the study. Furthermore, data collected will aid to sensitise the Ministry of Agriculture, Water and Land Reform; the Namibian Water Authority (NamWater), and the water management sector on the possible prevalence of groundwater pollution on the site of the study and possibly across the country. The results of the study will assist in the decision-making process in relation to groundwater conservation and management, and the need for general monitoring of groundwater quality across the country. Outcomes of the study will also contribute to the growing debate and knowledge, attitude, and practices on assessment of groundwater quality and its human health risk generally. Environmentalist and hydrologist will make use of the information contained herein as a reference point in addition to the available literature.

1.7 Aim of the study

The study assessed the effect of groundwater quality on human health in Ovitoto, Otjozondjupa region, Namibia.

1.8. Research objectives

The research objectives were as follows:

i. To analyse the physico-chemical and microbial characteristics of water sample in the study area.

ii. To assess human-health risks associated with the use of water in the study area.
iii. To develop intervention measures for water pollution mitigation and abatement.

1.9. Research questions

The study sought to answer the following research questions:

i. What is the physico-chemical and microbial characteristics of groundwater quality from Ovitoto, Otjozondjupa, Namibia?
ii. What are the human health risks associated with the utilisation of the groundwater for domestic purposes, including drinking?
iii. What mitigating measures can be proposed for the prevention of human health risks and exposure?

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Unclean drinking water can seriously affect human health, which may result in a financial burden on the government through healthcare treatment costs. Hence, access to potable water for domestic use is of greatest significance. Physico-chemical properties of drinking water, such as turbidity, pH, total suspended solids, temperature, chloride, , total dissolved solids (TDS), pathogens and heavy metals are important criteria that have an influence on water quality (Subin & Miji, 2013). The essential tool in the management of surface water, including groundwater is water quality monitoring. Hence, this study assessed physico-chemical and microbial characteristics of water samples. In addition, the study also assessed human health risks allied with the use of groundwater, and proposed intervention measures to mitigate and abate water pollution.

The main goal of this chapter is to review existing literatures including data, findings, and discussions, as well as other studies that are related to water quality monitoring and human health risk assessment in relation to the use of groundwater for domestic uses. Moreover, the review identified literature that provided evidence on the physico-chemical and microbial characteristics of groundwater and human health risk assessment allied with the use of groundwater. It also helped in justifying the reason for carrying out the research. The review has been chronologically presented following the physico-chemical and microbial characteristics of groundwater samples, assessment of human health risk associated with the use of groundwater – and finally, the development of intervention measures for the mitigation and abatement groundwater pollution.

2.2. Water quality analysis/determination

In a water quality assessment study that was conducted by Edokpayi, Odiyo, Popoola and Msadgati (2018) on the analysis of physico-chemical and microbiological parameters of another sources of drinking water from boreholes, the level of the turbidity, pH, temperature, total phosphorus, total nitrogen, total dissolved solid, chloride, electrical conductivity, fluoride, sulphate, and nitrate levels were found in line with the WHO recommended standard limits for drinking water. The methods that were used to determine the parameters were membrane filtration, multi-meter, and ion chromatography. However, the high level of pathogenic entities such as *Escherichia coli* and *Enterococci* were detected; hence, the water was not fit for drinking.

In another similar study involving the determination of water quality suitability and index and of municipal river for water supply by Aketeyon, Omotayo, Soladoye and Olaoye (2011), results revealed close contamination by domestic, agricultural, and industrial wastes with higher E.C and total hardness, while other parameters were below the WHO recommended t permissible limit for drinking water. Also, the result of the intended WQI indicated that the water is appropriate for domestic use.

Reddy and Nandini (2011) conducted a study on the physicochemical analysis of surface and groundwater in selected areas of Thummalapalli, where various parameters like pH, EMF, electrical conductivity, salinity, DO and TDS were carried out. The results indicated that all parameters were below the pollution levels, which is satisfactory of the requirement for the use of numerous purposes like domestic, industrial, and agricultural. It was explained that excessive salinity in groundwater affects the productivity of land, and lower salinity levels adversely affects vegetation growing in areas of shallow water.

Lastly, Angaleeswari and Valliammai (2017) study assessed groundwater quality, using water index in India, and it determined water quality based on 12 physico-chemical parameters like electrical conductivity (EC), pH, total dissolved solid (TDS), calcium, total hardness, Mg, (Magnesium), SO_4^{2-} (sulphate), Cl^- (Chloride), NO_3^- (Nitrate, F^- (Fluoride) and HCO_3^{2-} . The analysis was examined based on pre- and post-monsoon and comparison was done. The pH value was lower in dry season compared to the rainy season, and most of the pH values were found to be below the WHO recommended limit (1971 p.6-8). The results clearly showed that the first decade had good water quality conditions, compared to second decade and post-monsoon season – the area felt in better water quality condition as compared to pre-monsoon season.

2.3. Quantitative assessment of human health risks associated with the utilise of water

A study conducted by Edokpayi et al. (2019) on the evaluation of water quality and its human health assessment due to chemical contamination in groundwater around Mudedane area in Limpopo province, South Africa. The study looked at the chemical concentration of heavy metals in eight randomly selected boreholes in the above-mentioned area. The results were matched with the South African national recommended standard limit. Quantitative risk assessment was performed to further determine the effects of heavy metals on human health through dermal and ingestion absorption. This was done separately for children and adults to assess the amount of heavy metals in the borehole samples. Indicators such as nitrate, turbidity, iron, chromium, and manganese in some studied boreholes did not obey with recommended limits sets for human consumption. Hierarchical cluster analysis and principal component analysis showed that natural and human-made activities are the main cause of high heavy metal concentration in borehole water samples. The non-carcinogenic effects was calculated using hazard quotient toxicity potential, chronic daily intake and cumulative hazard index of groundwater through dermal and ingestion and absorption passageways were less than a unity, which indicated that drinking of the water could have slight or no major health risk. But, maximum estimated values for an individual were above the recommended limit. This may lead to possible health risk to children and adults in the examined area. Thus, continuous monitoring of groundwater in the examined area is highly recommended to avoid potential C-ring of people in the assessed area.

This is similar to a study that was conducted by Saleh (2019), in Iran on the risk assessment of carcinogenic and non-carcinogenic concentration of heavy metals in groundwater samples. The study focused on the Cr, As, Cu Cr, Fe, Zn, and Pb concentration in drinking water samples. This was assessed on the potential consumer's health risk of heavy metal intake. The Inductively Coupled Plasma Optical Emission Spectrometry method was used to analyse the heavy metal contamination in the water samples. These results were within WHO and Iranian national recommended limits. The contaminations of heavy metal index were evaluated based on the drinking water quality. Risk index done by was calculating the hazard quotient and chronic daily intake according to the United States Environmental Protection Agency approach. Heavy metal contamination in all the samples was less than 100, indicating it is a low-level heavy metal. In this paper, the maximum average of risk belonged to copper and lead and with the respective values of 6.10x$10^{-7}$and 33.99x$10^{-7}$from the assessed area. Thus, continuous monitoring and evaluation of drinking water resources in the examined area is highly recommended.

Another study contacted by Rahman et al. (2020) in China on groundwater quality and health risk assessment. Water samples were collected between January and July. In this study, six common physicochemical (permanganate index, pH, sulphate, ammonia, total dissolved solids, and hardness) and eight heavy metals of toxicological potential: fluorine (F-), manganese (Mn), Cadmium (Cd), Chromium (Cr), iron (Fe), lead (Pb), Copper (Cu) and selenium (Se) were analysed. About 6.7% of the analysed water samples were within the recommended limit for drinking water. Health risk-based investigation revealed non-carcinogenic effects with the consumption of ground water.

On the contrary, a study was contacted in China in 2018 on groundwater quality and risk assessment. In this studies agricultural water quality was assessed using various agricultural water quality parameters such as sodium adsorption ration (SAR), sodium percentage (%), salinity hazard, Kelley's ratio (KR) and magnesium hazard (MH) (Amalraj & Pius, 2018). A health risks-based investigation also revealed non-carcinogenic effects as well as the carcinogenic risk factor associated with the consumption of the groundwater.

2.4. Prevention of health risks from contaminated groundwater

Water quality is of vital importance, given the many diverse uses of water. The following are a few recommendations given by different researchers, which can also be applicable to the usage of groundwater (borehole water).

It is recommended to directly end the uses of polluted water to lessen the health risk, especially in cases where it is used for drinking purposes. Authorities or government entities should also ensure potable water supply to all, and the supply lines should be distant away from dumping sites, mining activities and sludge or drainage sites. Proper training on the usage of agrochemicals to avoid overuse or over application should be provided to the farmers. Again, knowledge through training programmes and awareness campaigns on the management and sustainable use t of groundwater should be provided to community members. This can be achieved by offering necessary guidance to farmers for proper crop fertilisation. "Other management measures may also include the installation of riparian vegetation and buffer strips near the boreholes. These have been found highly effective in preventing non-point source pollution from agricultural areas from entering groundwater and rivers" (Asadullah, Nisa & Khan, 2013 p.30)

For the sustainable management of water, sanitation programmes should be introduced through conservational awareness campaign in the communities along the borehole to reduce contamination of water resources and the spread of water related illness. Application of fertiliser should be provided to farmers to avoid high nutrient loads in water because of runoffs. Pesticide deposit analysis must also be supported to improve the controlling of agrochemicals (Karikari & Ansa-Asare, 2006).

A study conducted in Accra, Ghana, indicated that to ensure development in the quality and quantity of water resources, there is the need for realistic actions and sustainable measures to be put in place by the responsible authorities in the water industry to ensure development in the quantity and quality of water bodies (Lente, Keraita, Drechsel, Ofosu-Anim & Brimah, 2012). Lente et al. (2012) recommend that institutions such as the Community Water and Sanitation Agency and Water Company Limited should put in appropriate actions or platforms to ensure the quality of water provided to communities meets national and international standards.

2.5. Conclusion

Previous studies give a clear picture of what different researchers have done pertaining to groundwater quality monitoring and human health risk assessment. Most studies focused on physicochemical and microbial groundwater quality analysis, and only few studies focus on the human health risks assessment of groundwater (borehole). This review indicates that more research needs to be done because there are still many aspects to uncover. The next chapter deliberates on the methodology and approach used to collection and analysing of data.

CHAPTER 3: METHODOLOGY

3.1. Background of the study

This study focused on the borehole water quality monitoring and human health risk assessment in Ovitoto. Based on the Namibia Statistic Agency survey 2011, Ovitoto population is estimated to be around 6 000. There are about nine villages in the Ovitoto settlement, namely: Okasongua, Okomakuara, Okandjira, Ondamekondo, Okamuina, Ondamekondo 2, Oruuwa 01, Oruuwa 02 and Otjongombe. In each village, there is at least one functional borehole that supplies water to the community members. Members of the community are usually selected to be part of the committee that manages (pumps) the boreholes.

Various activities such as farming, agriculture and mining are common anthropogenic activities being carried out by residents in the study area. Majority of Ovitoto residents depend on animal farming for survival, an activity that also requires the provision and use of groundwater. Ovitoto is classified as an arid area. Zinc and manganese are being mined at Otozondu village, which is situated 30 kilometres to Ovitoto, posing a potential to negatively impact groundwater quality when poorly managed.

3.2. Study design

A research design is vital, as it helps in collecting the necessary information towards achieving the aim of the study. The research approach/design was qualitative (observational, interview-based) and experimental, involving the collection of water samples from the sampling stations (boreholes) and laboratory analysis.

3.3. Sampling, sampling frequency and sampling method

a) Sample collection procedure

Water samples were collected at nine (9) selected boreholes. Sampling followed a purposive/judgmental sampling procedure from various sampling stations (boreholes). Sampling stations are the boreholes at the following community settlements: kasongua, Okomakuara, Okandjiira, Ondamekondo, Okamuina, Ondamekondo 2, Oruuwa 01, Oruuwa 02 and Otjongombe. The distance among the boreholes is approximately 6 km.

Sampling: Bi-monthly water sampling/monitoring exercise was conducted within the months of March 2021 to July 2021. Samples were analysed in the laboratory to establish the physio-chemical and microbial parameters, and to assess possible human health risks that may be associated with the domestic use of water. Hence, a total of six (6) sets of data were collected at the end of study. A total of 108 water samples were collected for all the sampling sites, using a 200 ml sampling bottle during the sampling periods. Sterile water sampling bottles were used for microbiological samples. Water samples were collected from the boreholes by firstly letting the water to run for about 30 seconds, rinsing the bottle two times with a small portion of the water, and then filling the sample bottle to near full to allow for space. Sampling was carried out at almost the same time intervals for all the sampling sites in the morning. The bottles were reserved cool at 4^0C in cooler boxes and transported for analysis at the laboratory. Parameters such as TDS, temperature, EC and pH was determined on-site to ensure the quality of the results, using a portable multi-parameter water quality meter with serial number (HACH HI9828).

b) Sampling frequency

Twelve (12) water samples from each of the nine (9) boreholes were collected during the months of March 2021 and July 2021 on a bi-monthly basis. Hence, a total of 108 water samples were collected for all the sampling sites.

c) Sampling precautions

The precautions below were taken to avoid contamination of water samples during collection:

- Sterile sampling bottles were used.
- Sterile latex gloves were used to avoid contamination of sampling bottles by hands during handling and removal of bottle caps.
- During collection, the researcher made sure to avoid contact between the mouth of the bottle cap and the surface on which it is placed to avoid contamination.
- Sampling bottles were clearly marked on-site, where point names, location, date, time and types of analysis to be conducted were recorded.
- Sampling bottles were immediately sealed after collection to avoid external based contamination e.g., airborne particles.
- Sampling bottles were transported in a cooler box with the aid of ice packs in temperatures between 0-4 degrees Celsius to ensure the water is kept in the same state as it was collected, and to prevent microbial growth.
- Foam plastics were placed in the cooler box to avoid rigid contact between sampling bottles during transportation, which would cause bottles to break.
- Samples was analysed within an hour after collection.

Figure 2: *Water sample bottle and labelling from site.*

Figure 3: *Water samples at the laboratory receiving area.*

d) Sampling method

The non-probability sampling method was applied, where purposive sampling was used on the basis of the researcher's knowledge of the population. Convenience sampling was applied in the selection of the participants the study, based on their availability.

3.4. Exclusion and inclusion criteria

The study included only analysis and evaluation of microbiological indicators (faecal coliforms, *Escherichia coli* and total coliforms), using the Polymerase Chain Reaction (PCR) method and physio-chemical parameters (pH, TDS,T, EC, turbidity, colour, total hardness, sodium (Na), potassium (K), sulphate (SO_4^{2-}), silicate (SiO_2), fluoride (F^-), chloride (Cl^-), calcium carbonate ($CaCO_3$), magnesium (Mg), manganese (Mn), iron (Fe), cadmium (Cd), zinc (Zn) ,copper (Cu), nitrate ($N0_3^-$) and lead (Pb) using ion chromatography for the drinking water. Only operational sampling stations (boreholes) at each community settlement at the site of the study were sampled.

3.5. Data collection method

The data collected for the analysis was qualitative (observational and administered questionnaires) and experimental, involving the collection of data from physico-chemical and microbial analyses of water samples. Observational checklist, interview-based questions and administered questionnaires were also used in data collection processes. A laboratory analysis of water samples followed standard procedures as Alley (2000), describes. Data obtained from the study were applied to the Human Health Risk Assessment Equation to obtain the level of risk as USEPA (2001) recommends. Lastly, the researcher interviewed a leader of the community, a constituency councillor, a school principal from Oruuwa primary school and one community member.

3.5.1. Experimental

3.5.1.1 Analysed water quality parameters

The following microbiological and physico-chemical indicators were analysed: Faecal coliforms, Escherichia coli and total coliforms using the Polymerase Chain Reaction (PCR) method. TDS, pH, EC, temperature, turbidity, colour, total hardness, sodium (Na), potassium (K), sulphate (SO_4^{2-}), silicate (SiO_2), fluoride (F^-), chloride (Cl^-), calcium carbonate ($CaCO_3$), magnesium (Mg), manganese (Mn), iron (Fe), cadmium (Cd), zinc (Zn), copper (Cu), nitrate ($N0_3^-$) and lead (Pb) using portable multi-parameter and Inductively Couple-Plasma Emission Spectroscopy (ICP-OES). Samples were transported to the laboratory and analysed within 24 hours. In addition, parameters such as temperature, turbidity, pH, and conductivity were determined on-site to ensure quality of the results using a portable multi-parameter water quality meter with a serial number (HACH HI9828). Data obtained from the results were applied to the Risk Assessment Equation for human health to obtain the level of risk as USEPA (2001) recommends.

Parameters were evaluated based on various standards (Namibian Water Quality Standards for Namibia Water Corporation (NamWater); World Health Organisation guidelines for drinking water (WHO, 2006) for possible compliance with water quality criteria in relation to its uses. All collected data were analysed using SPSS Version 26. Correlation was used at different significant levels to identify variances among variables. These parameters should be present at certain acceptable levels or totally absent to avoid them from negatively affecting human health, thus ensuring that it is suitable for domestic use.

(a) Turbidity

Turbidity is often referred to as a secondary measure of total suspended solids (TSS), and it comprises mineral and organic elements that are transported in the water column. They are intricately associated to erosion. It is aesthetically unpleasant to consume turbid waters.

(b) Temperature

The chemical and biological features of water are largely affected by variation in temperature; general rise in water temperature can cause rise in biological and chemical reaction rates, growth of water organisms and mineral solubility. Drinking water must also be at a rational temperature and be free of unpleasant chemicals because they may be detrimental to human health if they are present at alarmingly high concentrations/levels (Shareef, Muhamad & Shekhani, 2009).

(c) pH

The biological efficiency in water systems is intricately related to water pH, and it is a significant factor in water treatment, as flocculation and coagulation procedures are particularly pH sensitive.

(d) Nitrate

The possible health threat of nitrate in water has steered to increased rigidity in nitrate monitoring of waters as it can be abridged to nitrite, which has been related to *Methamoglobinemia* in pregnant women and infants (Fatoki et al., 2001).

(e) Total Dissolved Solids

TDS is a vital measure in determining the suitability of water for drinking as it regulates the salinity of water. Magnesium, Sodium, and calcium were analysed. Calcium was analysed because extreme levels may cause the formation of gallbladder or kidney or stones. Sodium was analysed because excessive sodium intake in water and food has been well-known as a contributor to hypertension (Michael et al., 2002). Moreover, magnesium contributes to water hardness, and NamWater has a standard permission limit of 200mg/L in drinking water.

(f) Hardness

Hardness was measured due to its impacts on water treatment as well as problems it poses in agricultural and domestic use. The discharges of sewage and runoff from the area are the main factors distressing the microbiological quality of surface waters.

(g) Heavy metals

Exposure to heavy metals over prolonged periods is harmful to human health, as it can cause neurological damage, renal dysfunction, vomiting and headaches.

(i) *E. coli*/coliform

E. coli gives definite indication of current faecal contamination, and it must not be existing in drinking-water. *E. coli* is a beneficial parameter, but it has limits; protozoa and enteric viruses are more resilient to decontamination. Therefore, the absence of *E. coli* will not automatically specify liberty from these bacteria.

(h) Electrical conductivity

The total dissolved salts and ions in the water are estimated by amount of electrical conductivity.

3.5.2 Analysis

The aforementioned parameters were analysed in the collected water samples following a previously described process in a similar study (Alley, 2002).

3.5.2.1 Physico-chemical analysis

The physical indicators of the water samples were determined on site as stated above. The instrument undergoes standard calibration procedures according to the calibration documentation provided by the manufacturer. This was done to maximise the accuracy of desired results. The instruments that were used to analyse the parameters are presented in Table 1 below.

Table 1: Instruments used for analysis of physio-chemical parameters

Instrument name	Parameter	Model	Manufacturer	Serial #	Brand	Country of origin
Portable pH/EC/TDS/ temperature meter	Conductivity, TDS, pH, Temperature	HI 9811-5	HANNA Instrument	F00724223	HANNA	Romania
Portable turbid meter	Turbidity	TB200	Orbeco-Hellige	1766	Orbeco-Hellige	USA
Portable colorimeter II	Chlorine	14060501	HACH Company	16050E300 743	HACH	USA
ICP-OE Spectrometer	Heavy metals	Ice 3000 SERIES	NC	NC	NC	NC

NC = Not confirmed

3.5.2.2 Heavy metals analysis

Analysis of heavy metals in water sample was carried out following a previously described method (Cobbina et al., 2015).

3.5.2.2.1 Digestion of water samples for the analyses

One hundred millitre (100ml) of water samples were measured into a 250ml beaker and 5ml of concentrated nitric acid, where 5 ml of concentrated sulphuric acid was added. The beaker was heated slowly (slowly at low heat) on a hotplate until the concentration was reduced to approximately 15 to 20ml. The digested sample was removed from the hotplate and permitted to cool to room temperature. This was then filtered through Whatman 0.45µm filter paper into a 100ml standard flask and make up to the mark with deionised or double purified water, and then it was stored for analysis. The heavy metal content of the digested sample was determined using Couple-Plasma Emission Spectroscopy (ICP-OES).

3.5.2.2.2 Quality assurance

Quality control and assurance of the process was important to confirm the quality of results obtained. Firstly, all chemicals and reagents were of high purity. All glass wares were washed thoroughly with detergent and rinsed several times with deionised water. A blank digest as well as standard metal addition to pre-digested water samples to check for possible metallic interference.

3.5.2.3 Microbiological analysis of water samples

The researcher used various types of agar to determine the bacteria present in each water samples. Agar provides bacteria with the right nutrients and environment for growth, which makes it easier to analyse and identify specific bacteria in the collected samples. Bacteria have its specific agar medium in which it grows and multiplies. For instance, E. coli grows in TBX (Tryptone Bile Agar).

Figure 4: *Water samples in the microbiological lab.*

The water samples were first passed through a membrane filter, using a filter vacuum and funnel system, where any bacteria in the sample are trapped and concerted on the surface of the membrane. Trapped organism in the membrane was then put in a petri dish having desired growth medium.

To determine coliforms, the researcher used Plate Count Agar (PCA) to indicate the present in the water samples. The water was put on PCA plates in two different volumes, namely: 0.1ml and 1ml to measure the differences in the number of microbes in small volumes compared to a bigger one. The plates were then incubated at 30^{o}C for 24 hours. To establish the level of *E. coli* in the water samples, Tryptone Bile Agar (TBX) and Trypticase Soy Agar (TSA) was used, where two different volumes of water (0.1ml & 1.0ml) was placed on the plates. Similar to the procedure followed in the testing of *Total coliform*, the water was first filtered through a membrane filter. To be exact, the filters (with the samples) were first placed on TSA plates, where they were incubated for two hours at 30 degrees and later placed on TBX plates to be incubated at 45°C for 24 hours.

Figure 5: *Sorting and labelling of water samples.*

Figure 6: *Water samples in the incubation machine.*

3.5.2.4 Quantitative health risk assessment equation

Tracing metals contamination in human is done to determine the human exposure pathways of individual, it can happen via three main routes: through inhalation via nose, direct ingestion, and dermal absorption through skin exposure. The uptake of metals in terms of the estimated daily intake (EDI) was calculated through the estimation of exposure doses of the metals to assess the health risk that may occur (Makwe, 2012).

Estimated Daily Intake = metal conc. in water (mg/kg) X average daily water intake (average per capita of water uptake in kg/person/daily in Namibia is 1 litre)/ average body weight (av. Body weight of a Namibian is 59.58) (Makwe, 2012)

This was calculated with the following equation.

$$Exp_{ing} = \frac{C_{water} \times IR \times EF \times ED}{BW \times AT}$$

$$Exp_{derm} = \frac{(C_{water} \times SA \times KP \times ET \times EF \times ED \times CF)}{(BW \times AT)}$$

Exp_{ing}: exposure dose via ingestion of water $(mg/kg/day)$; Exp_{derm}: exposure dose through dermal absorption $(mg/kg/day)$; C_{water} : av. concentration of the assessed metals in water (μg/L) Ingestion rate in this study: IR (2.2 L/day for adults; 1.8 L/day for children); Exposure Frequency: EF (365 days/year);Exposure Duration: ED (70 years for adults; and 6 years for children); Average body weight: BW (70 kg for adults; 15 kg for children); Averaging time: AT (365 days/year × 70 years for an adult; 365 days/year × 6 years for a child); Exposed skin area: SA (18 000cm^2 for adults; 6 600cm^2 for children); Dermal permeability coefficient in water : Kp, (cm/h), 0.001 for Fe, Cu, Cd and Mn, while 0.0002 for Cr; 0.006 for Zn and 0.002 for Cr;Exposure time: Exposure time (0.58 h/day for adults; 1 h/day for children), and CF: unit conversion factor ($0.001\ L/cm^3$) (USEPA, 1989).

The exposures to heavy metals were calculated by equating the determined pollutant to determine possible non-carcinogenic exposures from each exposure route (dermal and ingestion) with the reference dose (RfD) to get the hazard quotient toxicity (HQ) possibility of an average daily intake to the reference dose for an individual through dermal and ingestion:

Hazard quotient equation (HQ)

$$HQ_{ing/derm} = \frac{Exp_{ing/derm}}{RfD_{ing/derm}}$$

Where $RfD_{ing/derm}$ is dermal/ingestion toxicity reference dose (mg/kg/day). The RfD_{ing} and RfD_{derm} values were acquired from the review of work done (Igbal & Shahh , 2013). HQ under 1 is perceived to be harmless, and it reserved as a vital non-carcinogenic [Igbal & Shahh, 2013], but HQ value above 1 may pose health related problem in relation with overexposure of individual to the pollutants. To measure the overall non-carcinogenic effects caused by more than one pathway and metal, the quantity of the calculated HQs by all metals were articulated as hazard index (HI). Health Index (HI) > 1 Showed that exposure to the borehole water may pose possible impacts on human health [Igbal & Shahh, 2013].

Hazard index equation (HI)

$$HI = \sum_{i=1}^{n} HQ_{ing/derm}$$

Where $HI_{ing/derm}$ is the hazard index through dermal or ingestion contact.

Chronic daily intake equation (CDI)

Chronic daily intake (CDI) of heavy metal via ingestion was calculated using the following equation:

$$CDI = C_{water} \times \frac{DI}{BW}$$

Where,C_{water}, average daily intake of water (1.8 L/day for children; 2.2L/day for adults) and body weight (15 kg for children; 70 kg for children) denote the concentration of trace metal in water in (mg/kg). Target Hazard Quotient was used to estimate the carcinogenic risk via an ingestion pathway.

Non-carcinogenic health risks index

The consumption of heavy metals was determined through Targeted Hazard Quotient (THQ) to establish the non-carcinogenic health concerns. Below is the ratio of Estimated Daily Intake (EDI) to that of Oral Reference Dose (*RfD*), and it was established using Chronic Daily Intake (CDI).

Targeted Hazard Quotient = Estimated Daily Intake /Oral Reference Dose

Targeted Hazard Quotient >1 shows an undesirable risk of non-carcinogenic impacts on health, while an Health Index <1 shows no risk of non-carcinogenic impacts on health.

Carcinogenic health risk index (CRI)

This is done to assess the potential harm of development of cancer from the drinking of pollutants in water. This was done following THQ.

Carcinogenic health risk index **=** Estimated Daily Intake /Carcinogenic slope factor

"Carcinogenic slope factor of metals in (mg/kg/day), a limit of $1.0x10^{-6}$ – $1.0x10^{-4}$ was anticipated as the permissible range (i.e., 1 in 10,000) for carcinogenic harm over a 70-year generation" (Igbal & Shahh, 2013).

3.6. Data management

The number of colonies in each plate (TBX and PCA) was counted for each microorganism (General coliforms and *E. coli*). The below formula was used to calculate the Colony-Forming Units (CFU/ml):

Colony-Forming Units (CFU/ml) = (Number of colonies × Dilution factor)/ (Volume plated)

After the calculation of data collected in CFU/ml, all collected data were analysed and managed by means of SPSS software (Version 26) and summarised in graphs and tables. In addition, descriptive data collected were analysed using excels sheets. Excel sheet was used to calculate the mean values of each parameter measured at all sampling sites. Correlation, one and two-way ANOVA was used at different significant levels to identify variances between variables. The results were then presented in appropriate graphs and tables.

3.7. Ethical Issues/considerations

Ethical clearance was sought from the constituency councillor's office – rural water department; the Ministry of Agriculture, Water and Forestry and the Namibia University of Science and Technology (NUST) Higher Degree Committee (HDC) to conduct the study.

3.8. Limitations

The researcher used nonprobability sampling (purposive sampling) to selecting the sampling sites. This might have introduced biasness in the study, as the results are not representative of all the boreholes located at the site of the study. The network coverage in the area was poor, which really made it hard to take the coordinates of the sampling sites. Late arrival of reagent to be used in the analysis of sample affected the interval time of data collection; the researcher changed the one-month gap to a three-week gap for the last three water sample collection. Lack of resources was a limitation, as the researcher found it difficult to acquire some equipment's for water sampling and transportation due to lockdown caused by Coronavirus 19 (COVID-19).

3.9. Conclusion

A research methodology is vital, as it helps in collecting the necessary information towards achieving the aim and objectives of the study. The study design was qualitative (observational, interview-based) and experimental, involving the collection of water samples from the sampling stations (boreholes) and laboratory analysis.

CHAPTER 4: RESULTS

Introduction

This section presents a narrative of the results of analysed water samples from the sampling points and calculation of health risk assessment (mathematical equations). The results are presented in tables and charts as appropriate for clarity and comprehension of results.

4.1. Results of physico-chemical and microbial analyses of water samples during sampling period I

Results of the physico-chemical analysis of analysed water samples from the boreholes from Ovitoto are presented in tabular form. Two samples were taken from each sampling point (borehole) (one for microbiology and the other for chemistry). During the first month of the trial, microbiological and chemistry water samples were collected but only chemistry was analysed.

Table 2: Results of heavy metals analysis (mg/L) in water samples from sampling period 1

SP	**Trace metals**						
		Zn	**Cd**	**Cu**	**Pb**	**Fe**	**Mn**
A		0.08	<0.01	0.01	<0.02	0.04	0.1
B		0.34	<0.01	0.01	<0.02	0.14	0.21
C		0.03	<0.01	<0.01	<0.02	<0.01	<0.01
D		8.3	<0.01	<0.01	<0.02	0.06	0.26
E		0.4	<0.01	0.01	<0.02	0.01	0.02
F		4.5	<0.01	0.01	<0.02	0.11	<0.01
G		0.58	<0.01	0.03	<0.02	16	0.83
H		1.8	<0.01	0.02	<0.02	66	84
I		0.24	<0.01	0.01	<0.02	0.01	<0.01

SP = Sampling Points; **A-I** = Sampling Sites where **A** = Oruuwa 01; **B** = Oruuwa 02; **C** = Otjongombe; **D** = Okasongua; **E** = Okomakuara; **F** = Okandjira; **G** = Ondamekondo 2; **H** = Ondamekondo; **I** = Okumuina;

Table 2 shows that a total number of eight metals were analysed in the water samples from the nine sampling points, using Atomic Absorption Spectrophotometry. The level of Na ranged between 16-395mg/L; K ranged between 4-24mg/L; Fe ranged between <0.01-66mg/L; Mn ranged between <0.01-8.4mg/L; Cu ranged between <0.01-0.03mg/L; Zn ranged between 0.03- 8.3mg/L; Cd levels were <0.01mg/L – and lastly, the level of Pb recorded was 0.02mg/L.

Table 3: Results of the level of ionic content (mg/L) in analysed water samples during sampling period I

SP	Trace Ions								
	$S0_4^{2-}$	$N0_3^-$	$N0_2^-$	$Si0_2^{2-}$	F^-	Cl^-	Alkalinity	Hardness	Ca^{2+}
A	78	6.7	<0.1	32	0.7	133	558	371	187.5
B	37	3	<0.1	25	0.7	129	528	391	192.5
C	2	0.8	<0.1	32	0.5	<1	176	136	90
D	330	71.7	<0.1	22	1.4	230	598	550	337.5
E	28	0.5	<0.1	13	0.6	37	272	103	70
F	4	2.6	<0.1	22	0.2	2	126	68	42.5
G	50	<0.5	<0.1	23	0.6	310	638	338	217.5
H	5	0.6	<0.1	21	0.5	9	860	414	415
I	2	1.9	<0.1	34	0.6	1	246	148	90

SP = Sampling Points; **A-I=**sampling sites**,** **A** = Oruuwa 01; **B** = Oruuwa 02; **C** = Otjongombe; **D** = Okasongua; **E**=Okomakuara; **F** = Okandjira; **G** = Ondamekondo 2; **H** = Ondamekondo; **I** = Okumuina

Table 3 shows that a total of ten ions were determined in the water samples from nine sampling sites. The level of SO_4 ranged between 2-330mg/L; NO_3- between <0.5-71.7mg/L; NO_2- levels were <0.1mg/L; SiO_2 ranged between 13-34mg/L; alkalinity ranged between 126-860mg/L; hardness ranged between 68-550mg/L, and Calcium ranged between 42.5-415mg/L. Alkalinity had the highest recording of 800mg/L, and the lowest was magnesium with only 25mg/L; Hardness levels ranged between 68- 550mg/L.

Table 4: Results of the physical indicators in analysed water samples during sampling period I

	pH	Temperature (°C)	Turbidity (NTU)	EC (µS/cm)	TDS (mg/l)
Mean	7.4	20.3	175.0	130.7	875.9
Maximum	7.8	21.5	1280	302	2023.4
Minimum	6.8	20.3	0.36	28.4	190.3

Table 4 shows the average results of the physical parameters from all nine sampling points analysed in the samples from the Ovitoto groundwater (borehole) throughout the first sampling period. The pH had a mean value of 7.38, a minimum of 6.8 and a maximum of 7.8. Temperature readings were mean-20.3°C, minimum-20.3°C and maximum of 21.5°C. The highest level of turbidity recorded was

1280NTU, the lowest level was 0.363NTU and the mean was 174.99NTU. EC had a minimum of 28.4µS/cm, a maximum of 302µS/cm and a mean of 130.733µS/cm. Lastly, TDS had a maximum recording of 2023.4mg/L, a minimum of 190.25mg/L and a mean of 875.91mg/L.

4.2. Results of the physico-chemical and microbial analysis of water samples during sampling period II

Results of the analysis of water samples during the second period of sampling (21 April 2021) are presented below in appropriate tables and charts.

Table 5: Result of Heavy metals (mg/L) analysis in water samples during sampling period II

SP	Trace metals					
	Zn	**Cd**	**Cu**	**Pb**	**Fe**	**Mn**
A	0.06	0.01	0.01	0.02	0.02	0.15
B	0.53	0.01	0.01	0.02	0.05	0.03
C	0.05	0.01	0.01	0.02	0.01	0.01
D	6.4	0.01	0.01	0.02	0.02	0.35
E	0.23	0.01	0.01	0.02	0.02	0.03
F	0.31	0.01	0.01	0.02	0.01	0.01
G	0.69	0.01	0.01	0.02	52	10.3
H	0.88	0.01	0.01	0.02	50	10
I	0.18	0.01	0.01	0.02	0.01	0.01

SP = Sampling Points; **A-I**=sampling sites; **A** = Oruuwa 01; **B** = Oruuwa 02; **C** = Otjongombe; **D** = Okasongua; **E** = Okomakuara; **F** = Okandjira; **G** = Ondamekondo 2; **H** = Ondamekondo; **I** = Okumuina

Table 5 shows the level of Na ranged between 20-425mg/L; K ranged between 6-28mg/L; Fe ranged between <0.01-52.0mg/L; Mn ranged between <0.01-10.3mg/L; Cu levels were <0.01mg/L; Zn ranged between 0.05- 6.4mg/L; Cd levels were <0.01mg/L – and lastly, the level of Pb recorded was <0.02mg/L.

Table 6: Result of the microbial entities in analysed water samples during sampling period II

SP	**Microbial entities**			
	HT	Tc	Faecal coliform	**Remarks**
A	93	3	ND	Group B
B	97	15	ND	Group C
C	960	1	ND	Group B
D	4608	4	ND	Group C
E	185	ND	ND	Group B
F	555	ND	ND	Group B
X	1083	3.83	ND	
WHO limits	100	0	0	

A = Okamuina; **B =** Okomakuara; **C =** Okandjira; **D =** Okasongua; **E=**Ondamekondo; **F =** Ondamekondo 2; **HT** = Heterotrophic plate count/1 ml; ***Tc*** = *Total coliforms count*/100 ml; *Fc=Faecal coliform count/100 ml*; **ND** = Not detected

Table 6 shows that three microbial entities were determined in the water samples from six sampling points; the results are as follows: *Heterotrophic plate count* ranged between 93-4608cfu/ml, *Total Coliform* count ranged between 1-15cfu/ml and the *Faecal coliform* count was not spotted in all the samples from all the sampling sites.

Table 7: Results of the level of ionic content (mg/L) in analysed water samples during sampling period II

SP	**Trace ion**								
	$S0_4^{2-}$	**$N0_3^-$**	**NO_2^-**	**$Si0_2^{2-}$**	**F^-**	**Cl^-**	**Alkalinity**	**Hardness**	**Ca**
A	73	5.6	<0.1	34	0.9	164	562	428	208
B	31	13.1	<0.1	33	0.7	205	554	527	248
C	5	<0.5	<0.1	33	0.5	3.0	176	1461	100
D	420	44.3	<0.1	22	1.4	240	584	628	378
E	31	1.1	<0.1	14	0.8	46.0	276	106	85
F	8	1.7	<0.1	23	0.4	3.0	138	67	50
G	<1	1.1	<0.1	23	0.6	20.0	924	738	513
H	<1	1.6	<0.1	23	0.6	19.0	894	721	500
I	5	1.6	<0.1	35	0.6	5.0	246	157	103

SP = Sampling Points; A-I=sampling sites; **A** = Oruuwa 01; **B** = Oruuwa 02; **C** = Otjongombe; **D** = Okasongua; **E** = Okomakuara; **F** = Okandjira; **G** = Ondamekondo 2; **H** = Ondamekondo; **I** = Okumuina

Table 7 shows that a total of ten ions were determined in the samples from the above nine sampling sites. The level of SO_4 varies between <1 - 420mg/L; NO_3^- between < 0.5 - 13.1mg/L, NO_2^- levels were <0.1mg/L; SiO_2 ranged between 14-35mg/L; alkalinity ranged between 138-924mg/L; hardness ranged between 67-1461mg/L and calcium concentration ranged between 85-500mg/L.

Table 8: Result of the physical parameters present in analysed water samples from during sampling period II

	pH (pH unit)	**temperature (°C)**	**turbidity (NTU)**	**EC (µS/cm)**	**TDS (mg/l)**
Mean	7.4	20.02	208.4	122.7	821.9
Minimum	6.8	18.2	0.408	31	207.7
Maximum	7.7	22.1	984	273	1829.1

Table 8 shows the average results of the physical parameters from all nine sampling points analysed in the samples from the Ovitoto groundwater (boreholes) throughout the second sampling period (21 April 2021). The pH had a mean value of 7.4, a minimum of 6.8 and a maximum of 7.7. Temperature readings were mean 20.02°C, minimum 18.2°C and maximum of 22.1°C. The highest level of turbidity recorded was 984NTU, the lowest level was 0.408NTU, and the mean was 208.38NTU. EC had a minimum of 31µS/cm, a maximum of 273µS/cm and a mean of 122.67µS/cm. Lastly, TDS had a maximum recording of 1829.1mg/L, a minimum of 207.7mg/L and a mean of 821.94mg/L.

4.3. Results of physico-chemical and microbial analyses of water samples during sampling period III

Table 9: Result of Heavy metals analysis (mg/L) in water samples from the sampling period III (19 May 2021)

SP	**Trace metals**					
	Zn	**Cd**	**Cu**	**Pb**	**Fe**	**Mn**
A	0.09	0.01	0.01	0.02	0.02	0.02
B	0.02	0.01	0.01	0.02	0.02	0.14
C	0.02	0.01	0.01	0.02	0.01	0.01
D	3.3	0.01	0.01	0.02	0.03	0.27
E	0.14	0.01	0.01	0.02	0.01	0.04
F	0.21	0.01	0.01	0.02	0.02	0.01
G	1.02	0.01	0.02	0.02	37	8.3
H	0.95	0.01	0.01	0.02	41	7.6
I	0.13	0.01	0.01	0.02	0.02	0.01

SP = Sampling Points; A-I=sampling sites; **A** = Oruuwa 01; **B** = Oruuwa 02; **C** = Otjongombe; **D** = Okasongua; **E** = Okomakuara; **F** = Okandjira; **G** = Ondamekondo 2; **H** = Ondamekondo; **I** = Okumuina

Table 9 shows a total number of eight metals were analysed in the water samples from the above nine sampling points, using Atomic Absorption Spectrophotometry. The level of Na ranged between 15-210mg/L; K ranged between 5-29mg/L; Fe ranged between 0.01-41mg/L; Mn ranged between <0.01-8.3mg/L; Cu levels ranged between 0.01-0.02mg/L; Zn ranged between 0.02- 3.3mg/L; Cd levels were <0.01mg/L – and lastly, the level of Pb recorded was <0.02mg/L.

Table 10: Result of the microbial entities in analysed water samples during sampling period III

SP	**Microbial Entities**				
		E. coli	Tc	Faecal coliform	**Remarks**
A		ND	ND	ND	Group A
B		ND	1414	ND	Group D
C		ND	127	ND	Group C
D		ND	12	ND	Group B
E		ND	1	ND	Group B
F		ND	ND	ND	Group A
G		3	99	3	Group C
H		ND	1	ND	Group B
I		ND	579	ND	Group D
	X	3	319	3	
	WHO limits	0	0	0	

A = Okamuina; **B** = Okandjira; **C** = Okasongua; **D** = Okamakuara; **E** = Ondamekondo **F** = Ondamekondo 2; **G** = Oruuwa 01; **H** = Oruuwa 02; **I** = Otjongombe*; **E. coli** = Escherichia coli* in ml; ***Tc*** = *Total coliforms count/100 ml*; ***Faecal coli*** = *Faecal coliform count/100 ml*; **D** = Not detected

Table 10 shows that three microbial entities were analysed in the water samples from nine sampling point; the results are as follows: *Total coliforms count* ranged between 1-1414cfu/ml; *Faecal coliform counts* were only detected in one sample at the Oruuwa 02 with a value of 3 and *E. coli* was also detected only in one sample from Oruuwa 02 (Value-3).

Table 11: Results of the level of ionic content (mg/L) in analysed water samples during sampling period III

SP	Trace ions								
	$S04^{2-}$	$N0_3^-$	NO_2^-	SiO_2^{2-}	F^-	Cl^-	Alkalinity	Hardness	Ca^{2+}
A	83	6.8	<0.1	34	0.7	154	532	414	198
B	45	14.4	<0.1	32	0.7	210	522	536	253
C	5	1.8	<0.1	35	0.5	<0.1	162	138	100
D	390	30.4	<0.1	23	1.3	200	550	623	365
E	29	1.9	<0.1	14	0.8	44.0	260	88	75
F	6	2.2	<0.1	23	0.3	<1.0	130	58	45
G	27	1.5	<0.1	26	0.7	27.0	842	718	485
H	27	1.7	<0.1	26	0.7	27.0	846	718	485
I	14	1.9	<0.1	34	0.6	1.0	236	143	93

SP = Sampling Points; A-I= sampling sites; **A** = Oruuwa 01; **B** = Oruuwa 02; **C** = Otjongombe; **D** = Okasongua; **E** = Okomakuara; **F** = Okandjira; **G** = Ondamekondo 2; **H** = Ondamekondo; **I** = Okumuina

Table 11 shows that a total of ten ions were determined in the samples from the nine sampling sites above. The level of SO_4 varies between 5-390mg/L; NO_3- between 1.7-30.4mg/L; NO_2- levels were <0.1mg/L; SiO_2 ranged between 14-35mg/L; $CaCO_3$ levels, which represented alkalinity, hardness, calcium, and magnesium concentration ranged between (10-846; 58-718; 45-485; 13-283mg/L. Alkalinity had the highest recording of 846mg/L, and the lowest was magnesium with only 13mg/L.

Table 12: Result of the physical parameters in analysed water samples during sampling period III

	pH	Temperature (°C)	Turbidity (NTU)	EC (µS/cm)	TDS (mg/l)
Mean	7.6	19.0	174	124.5	834.6
Minimum	7.0	18.5	0.44	31.2	209.0
Maximum	7.9	23.3	811	264	1162.5

Table 12 presents the average results of the physical parameters from all nine sampling points analysed in the samples from the Ovitoto groundwater (boreholes) throughout the third sampling period (19 May 2021). The pH had a mean value of 7.6; a minimum of 7.0 and a maximum of 7.9. Temperature readings were mean 19.0°C, minimum 18.5°C and a maximum of 23.3°C. The highest level of turbidity recorded was 811NTU; the lowest level was 0.44NTU and the mean was 174NTU. EC had a minimum of 31.2µS/cm, a maximum of 264µS/cm and a mean of 124.5µS/cm. Lastly, TDS had a maximum recording of 1162.45mg/L, a minimum of 209.04mg/L and a mean of 834.62mg/L.

4.4. Results of physico-chemical and microbial analyses of water samples during sampling period IV

Table 13: Results of heavy metals analysis in water samples from sampling period IV (02 June 2021)

SP	**Trace metals**					
	Zn	**Cd**	**Cu**	**Pb**	**Fe**	**Mn**
A	0.07	0.01	0.01	0.02	0.04	0.05
B	0.6	0.01	0.01	0.02	0.08	0.02
C	0.03	0.01	0.01	0.02	0.01	0.01
D	3.5	0.01	0.01	0.02	0.05	0.23
E	0.73	0.01	0.01	0.02	0.05	0.05
F	0.4	0.01	0.01	0.02	0.03	0.03
G	0.14	0.01	0.01	0.02	45	8.6
H	0.07	0.01	0.01	0.02	17.8	8.4
I	0.27	0.01	0.01	0.02	0.03	0.01

SP = Sampling Points; A-I=sampling sites; **A** = Oruuwa 01; **B** = Oruuwa 02; **C** = Otjongombe; **D** = Okasongua; **E** = Okomakuara; **F** = Okandjira; **G** = Ondamekondo 2; **H** = Ondamekondo; **I** = Okumuina

Table 13 shows a total number of eight metals were analysed in the water samples from the nine sampling points above, using Atomic Absorption Spectrophotometry. The level of Na ranged between 18-340mg/L; K ranged between 6-25mg/L; Fe ranged between 0.01-45.0mg/L; Mn ranged between <0.01-8.6mg/L; Cu levels were <0.01mg/L; Zn ranged between 0.03-3.5mg/L; Cd levels were <0.01mg/L– and lastly, the level of Pb recorded was <0.02mg/L.

Table 14: Result of the microbial entities in analysed water samples during sampling IV

SP	Microbiological entities					
		HT	Tc	Faecal coli	*E. coli*	**Remarks**
A		1963	1	ND	ND	Group C
B		1237	10	1	1	Group C
C		619	5	N/D	ND	Group B
D		125	5	N/D	ND	Group B
E		184	N/D	N/D	ND	Group B
F		126	1	ND	ND	Group B
G		427	165	1	1	Group B
H		146	38	5	5	Group C
I		1045	5	N/D	ND	Group C
	X		3	319	3	
	WHO limits		0	0	0	

A = Okamuina; **B** = Okandjira; **C** = Okasongua; **D** = Okamakuara; **E** = Ondamekondo; **F** = Ondamekondo 2; **G** = Oruuwa 01; **H** = Oruuwa 02; **I** = Otjongombe; ***HT** = Heterotropic plate count; **E. coli** = Escherichia coli in ml*; ***Tc** = Total coliforms count/100 ml*; ***Faecal coli** = Faecal coliform count/100 ml*; **ND** = Not detected

Table 14 shows four microbial entities were determined in the samples from the nine sampling points above; the results are as follows: *Heterotrophic plate count* ranged between 125-1963cfu/ml; *Total coliforms count* ranged between 0-165cfu/ml; *Faecal coliform count ranged* from 0-5cfu/ml and *E.coli* ranged between 0-5cfu/ml.

Table 15: Results of the level of ionic content (mg/L) in analysed water samples during sampling point IV

SP	Trace ions								
	$S04^{2-}$	$N0_3^-$	NO_2^-	SiO_2^{2-}	F^-	Cl^-	Alkalinity	Hardness	Ca^{2+}
A	88	7.4	<0.1	34	0.7	161	532	200	180
B	47	12.6	<0.1	32	0.7	168	516	245.83	212.5
C	10	0.7	<0.1	33	0.5	<1	168	37.5	92.5
D	320	48.3	<0.1	21	1.1	191	520	258.3	310
E	48	5.5	<0.1	16	0.6	73	322	50	157.5
F	11	2.6	<0.1	24	0.3	2	134	16.66	52.5
G	15	<0.5	<0.1	25	0.7	25	858	212.5	442.5
H	22	<0.5	<0.1	25	0.7	27	852	208.4	455
I	19	2.3	<0.1	35	0.6	1	240	50	90

SP = Sampling Points; A-I=sampling sites; **A** = Oruuwa 01; **B** = Oruuwa 02; **C** = Otjongombe; **D** = Okasongua; **E** = Okomakuara; **F** = Okandjira; **G** = Ondamekondo 2; **H** = Ondamekondo; **I** = Okumuina

Table 15 shows a total of nine ions were analysed in the water samples from the above nine sampling points. The level of SO_4 ranged between 11-320mg/L; NO_3- between <0.5-48.3mg/L; NO_2- levels were <0.1mg/L; SiO_2 ranged between 16-35mg/L; $CaCO_3$ levels, which represented alkalinity, hardness, calcium and magnesium concentration, ranged between (134-858; 52.5-455; 37.5-258.33mg/L. Alkalinity had the highest recording of 858mg/L, and the lowest was magnesium with only 37.5mg/L.

Table 16: Results of the physical parameters in analysed water samples during sampling period IV

	pH	Temp (°C)	Turbidity (NTU)	EC (µS/cm)	TDS (mg/l)
Mean	7.6	23.1	164.0	125.3	840.1
Minimum	6.8	18.3	0.337	31.7	212.4
Maximum	8	25.5	758	260	1114.9

Table 16 shows the average results of the physical parameters from all nine sampling points analysed in the samples from the Ovitoto groundwater (boreholes) throughout the third sampling period IV. The pH had a mean value of 7.6, a minimum of 6.8 and a maximum of 8. Temperature readings were a mean 23.1°C, minimum 18.3°C and maximum of 25.5°C. The highest level of turbidity recorded was

758NTU, the lowest level was 0.337NTU and the mean was 164.00NTU. EC had a minimum of 31.7µS/cm, a maximum of 260µS/cm and a mean of 125.3µS/cm. Lastly, TDS had a maximum recording of 1114.88mg/L, a minimum of 212.39mg/L and a mean of 840.1mg/L.

4.5. Results of physico-chemical and microbial analyses of water samples during sampling period V

Table 17: Results of Heavy metals analysis in water samples from Ovitoto-boreholes during sampling period V (28 June 2021)

SP	**Trace metals**					
	Zn	**Cd**	**Cu**	**Pb**	**Fe**	**Mn**
A	0.01	0.01	0.01	0.02	0.01	0.01
B	0.05	0.01	0.01	0.02	0.08	0.02
C	0.02	0.01	0.01	0.02	0.01	0.01
D	2.1	0.01	0.01	0.02	0.02	0.2
E	0.23	0.01	0.01	0.02	0.01	0.05
F	0.43	0.01	0.01	0.02	0.02	0.01
G	0.42	0.01	0.01	0.02	2.86	6.6
H	0.4	0.01	0.01	0.02	2.76	6.4
I	0.31	0.01	0.01	0.02	0.01	0.01

SP = Sampling Points; A-I=sampling sites; **A** = Oruuwa 01; **B** = Oruuwa 02; **C** =Otjongombe; **D** = Okasongua; **E** = Okomakuara; **F** = Okandjira; **G** = Ondamekondo 2; **H** = Ondamekondo; **I** = Okumuina

Table 17 shows a total number of eight metals were analysed in the water samples from nine sampling points, using Atomic Absorption Spectrophotometry. The level of Na ranged between 17-320mg/L; K ranged between 8-32mg/L; Fe ranged between 0.01-2.86mg/L; Mn ranged between <0.01-6.6mg/L; Cu levels were <0.01mg/L; Zn ranged between <0.01-2.1mg/L; Cd levels were <0.01mg/L and lastly, the level of Pb recorded was <0.02mg/L.

Table 18: Result of the microbial analysis in water samples from Ovitoto boreholes during sampling period V (28 June 2021- second round of water sample collection in June)

SP	**Microbial Entities**					
		HT	Tc	Faecal coli	*E.coli*	**Remarks**
A		1963	1	ND	ND	Group C
B		1237	10	1	1	Group C
C		619	5	N/D	ND	Group B
D		125	5	N/D	ND	Group B
E		184	N/D	N/D	ND	Group B
F		126	1	ND	ND	Group B
G		427	165	1.0	1.0	Group B
H		146	38	5.0	5.0	Group C
I		1045	5	N/D	ND	Group C
	X	652.44	14.4	0.7	0.7	
	WHO limits		0	0	0	

A = Okamuina; A-I=sampling sites; **B** = Okandjira; **C** = Okasongua; **D** = Okamakuara; **E** = Ondamekondo **F** = Ondamekondo 2; **G** = Oruuwa 01; **H** = Oruuwa 02; **I** = Otjongombe; ***E.coli*** *= Escherichia coli in ml*; ***Tc*** *= Total coliforms count/100 ml*; ***HT =*** *Heterotrphic plate count*; ***faecal coli*** *= Faecal coliform count/100 ml;* **ND** = Not detected.

Table 18 shows four microbial entities were analysed in the water samples from the above nine sampling points; the results are as follows: *Heterotrophic plate count* ranged between 125-1963cfu/ml; *Total coliforms count* ranged between 0-165cfu/ml; *Faecal coliform count ranged* from 0-5cfu/ml and *E. coli* ranged between 0-5cfu/ml.

Table 19: Results of the level of ionic content (mg/L) in analysed water samples during sampling V

SP	Trace ions								
	$S04^{2-}$	$N0_3^-$	NO_2^-	SiO_2^{2-}	F^-	Cl^-	Alkalinity	Hardness	Ca^{2+}
A	97	7.3	0.2	34	0.8	165	447	204.16	127.5
B	78	13.5	<0.1	33	0.8	167	454	250	240
C	4	1.9	<0.1	34	0.5	3	162	45.83	100
D	360	57.9	<0.1	24	1.3	195	442	276.16	370
E	41	3.3	<0.1	25	0.8	71	264	37.5	112.5
F	4	<0.5	<0.1	5	0.3	3	130	20.83	50
G	14	<0.5	<0.1	30	0.7	23	842	225	492.5
H	16	1	<0.1	30	0.7	22	848	220.83	475
I	8	1.9	<0.1	34	0.6	2	254	58.35	102.9

SP = Sampling Points; A-I=sampling sites; **A** = Oruuwa 01; **B** = Oruuwa 02; **C** =Otjongombe; **D** = Okasongua; **E**= Okomakuara; **F** = Okandjira; **G** = Ondamekondo 2; **H** = Ondamekondo; **I** = Okumuina

Table 19 shows a total of nine ions were analysed in the water samples from nine sampling points. The level of SO_4 ranged between 4-360mg/L; NO_3- between <0.5-57.9mg/L; NO_2- levels ranged from <0.1-0.2mg/L; SiO_2 ranged between 5-34mg/L; $CaCO_3$ levels, which represented alkalinity, calcium and magnesium concentration, ranged between (130-848; 50-492.5; 20.83-276.16mg/L. Alkalinity had the highest recording of 848mg/L, and the lowest was magnesium, with only 37.5mg/L.

Table 20: Results of the physical parameters in analysed water samples during sampling period V

	pH	Temp (°C)	Turbidity (NTU)	EC (µS/cm)	TDS (mg/l)
Mean	8.4	24.0	79.36	137.2	805.7
Minimum	8.1	20.5	0.179	32.1	215.07
Maximum	8.7	26.7	356	159.9	1071.33

Table 20 presents the average results of the physical parameters from all nine sampling points analysed in the samples from the Ovitoto groundwater boreholes throughout the fifth sampling period V (28 June 2021-. The pH had a mean value of 8.4, a minimum of 8.1 and a maximum of 8.7. Temperature readings were mean 24.0°C, minimum 20.8 °C and maximum of 26.7 °C. The highest level of turbidity recorded was 356NTU, the lowest level was 0.176NTU and the mean was 79.36NTU. EC had a minimum of 32.1µS/cm, a maximum of 159.9µS/cm and a mean of 137.2µS/cm. Lastly, TDS had a maximum recording of 1071.33mg/L, a minimum of 215.07mg/L and a mean of 805.7mg/L.

4.6. Results of physico-chemical and microbial analyses of water samples during sampling period VI

Table 21: Results of heavy metals analysis (mg/L) in water samples from sampling period VI (20 July 2021)

SP	Trace metals					
	ZN	**Cd**	**Cu**	**Pd**	**Fe**	**Mn**
A	0.06	0.01	0.01	0.02	0.18	0.01
B	0.01	0.01	0.01	0.02	0.04	0.01
C	0.03	0.01	0.01	0.02	0.01	0.01
D	2.77	0.01	0.01	0.02	0.02	0.15
E	0.14	0.01	0.01	0.02	0.01	0.03
F	0.35	0.01	0.01	0.02	0.02	0.01
G	0.11	0.01	0.01	0.02	0.8	6
H	0.11	0.01	0.01	0.02	1.8	6.8
I	0.16	0.01	0.01	0.02	0.01	0.01

SP = Sampling Points; A-I=sampling site; **A** = Oruuwa 01; **B** = Oruuwa 02; **C** =Otjongombe; **D** = Okasongua; **E** = Okomakuara; **F** = Okandjira; **G** = Ondamekondo 2; **H** = Ondamekondo; **I** = Okumuina

Table 21 shows a total of eight metals were analysed in the water samples from the nine sampling points above, using Atomic Absorption Spectrophotometry. The level of Na ranged between 19-330mg/L; K ranged between 9-171mg/L; Fe ranged between <0.01-1.8mg/L; Mn ranged between <0.01-6.8mg/L; Cu levels were <0.01mg/L; Zn ranged between <0.01-2.77mg/L; Cd levels were <0.01mg/L – and lastly, the level of Pb recorded was <0.02mg/L.

Table 22: Results of the microbial entities in analysed water samples during sampling period VI

SP	Microbial entities					
		HT	Tc	Faecal coli	*E. coli*	**Remarks**
A		2880	16	N/D	N/D	Group C
B		3264	>201	43	43	Group D
C		1003	43	N/D	N/D	Group C
D		202	4	N/D	N/D	Group B
E		19	N/D	N/D	N/D	Group A
F		61	N/D	N/D	N/D	Group A
G		109	14	N/D	N/D	Group B
H		448	>201	N/D	N/D	Group D
I		896	>201	8	8	Group D
	X	986.8	75.5	5.6	5.6	
	WHO limits		0	0	0	

A = Okamuina; **B** = Okandjira; **C** = Okasongua; **D** = Okamakuara; **E** = Ondamekondo; F=Ondamekondo 2; **G** = Oruuwa 01; **H** = Oruuwa 02; **I** = Otjongombe; ***E.coli*** *= E. coli in ml;* ***Total coli*** *= Total coliforms count/100 ml;* ***fc*** *= Faecal coliform count/100ml*; ND= Not detected

Table 7b shows that four microbial entities were identified in the water samples from the nine sampling points above; the results are as follows: *Heterotrophic plate count* ranged between 19-3264cfu/ml; the *total coliforms count* ranged between 0->201cfu/ml; *Faecal coliform count* ranged from 0-0cfu/ml, and *E.coli* ranged between 0-8cfu/ml.

Table 23: Results of ions present in analysed in water samples during sampling period VI

SP	Trace ions									
		$S04^{2-}$	$N0_3^-$	NO_2^-	SiO_2^{2-}	F^-	Cl^-	Alkalinity	Hardness	Ca^{2+}
A		60	21.5	<0.1	34	0.7	210	528	266.66	252.5
B		109	9.6	<0.1	33	0.7	173	536	241.66	220
C		5	1.2	<0.1	36	0.5	<1	168	37.5	97.5
D		380	49.9	<0.1	26	1.4	200	546	250	345
E		33	2.4	<0.1	17	0.8	47	268	25	87.5
F		6	3.5	<0.1	28	0.3	2	158	29.16	80
G		18	<0.5	<0.1	33	0.7	30	824	225	472.5
H		22	1	<0.1	33	0.8	31	830	220.83	470
I		5	2.4	<0.1	37	0.6	4	242	45.83	95
	X	70.8	10.2	10.2	30.7	0.72	77.5	455.5	149.1	235.5
	WHO limits	-	10.0	-	-	1.5	250.0	500	500	200

SP = Sampling Points; A-I=sampling sites; **A** = Oruuwa 01; **B** = Oruuwa 02; **C** = Otjongombe; **D** = Okasongua; **E** = Okomakuara; **F** = Okandjira; **G** = Ondamekondo 2; **H** = Ondamekondo; **I** = Okumuina

Table 7c shows a total of nine ions were analysed in the water samples from the nine sampling points above. The level of SO_4 ranged between 4-380mg/L; NO_3- between <0.5-49.9mg/L; NO_2- levels were <0.1mg/L; SiO_2 ranged between 17-37mg/L; $CaCO_3$ levels, which represented alkalinity, calcium, and magnesium concentration, ranged between (158-830; 80-472.5; 25-266.66mg/L. Alkalinity had the highest recording of 830 mg/l, and the lowest was magnesium, with only 25mg/L.

Table 24: Results of the physical parameters in analysed water samples during sampling period VI

	pH	Temp (°C)	Turbidity (NTU)	EC (µS/cm)	TDS (mg/l)
Mean	7.5	22.7	71.3	122.1	818.7
Minimum	6.8	21.2	0.23	36.2	242.5
Maximum	8.1	25.2	319	256	1200.6

Table 7d shows the average results of the physical parameters from all nine sampling points analysed in the r samples from the Ovitoto groundwater (boreholes) throughout the sixth sampling period VI (28July 2021). The pH had a mean value of 7.5, a minimum of 6.8 and a maximum of 8.1. Temperature readings were mean 22.70°C, minimum 21.2°C and maximum of 25.2°C. The highest level of turbidity recorded was 319NTU, the lowest level was 0.234NTU and the mean was 71.3NTU. EC had a minimum of 36.2µS/cm, a maximum of 256µS/cm and a mean of 122.1µS/cm. Lastly, TDS had a maximum recording of 1200.64mg/L, a minimum of 242.54mg/L and a mean of 818.66mg/L.

4.7. Quantitative health risk assessment

Table 25: Cumulative level mean of trace metals (mg/L) in water samples from sampling point A across the sampling periods

SP	**Trace metals**					
	Zn	Cd	Cu	Pb	Fe	Mn
I	0.08	<0.01	0.01	<0.02	0.04	0.1
II	0.34	<0.01	0.01	<0.02	0.14	0.21
III	0.03	<0.01	<0.01	<0.02	<0.01	<0.01
IV	8.3	<0.01	<0.01	<0.02	0.06	0.26
V	0.4	<0.01	0.01	<0.02	0.01	0.02
VI	4.5	<0.01	0.01	<0.02	0.11	<0.01
X	**2.2**	**0.01**	**0.01**	**0.02**	**0.06**	**0.1**
WHO Limit	**5.0**	**5.0**	**1.0**	**0.01**	**0.3**	**0.1**

A=Oruuwa 01; SP=Sampling period; X= Mean level; WHO= World Health Organisation

Table 25 shows the cumulative level mean of trace metals in analysed water samples from Oruuwa 01 borehole across the sampling periods. The mean levels were compared to WHO standard limit. Based on the analysis across the sampling period all the metals were within the WHO standard expect Pb (lead)**.** Pb is viewed as non-essential, contaminated metals with harmful health concern in human. Lead has been associated in undesirable impacts on the cardiovascular system, the Central Nervous System (CNS), as well as on the immune system. Prolong drinking of this water may cause above health-related issue due to high level of lead.

Table 26: Cumulative level mean of trace metals (mg/L) in water samples from sampling point B across the sampling periods

SP	Trace metals					
	Zn	Cd	Cu	Pb	Fe	Mn
I	0.34	<0.01	0.01	<0.02	0.14	0.21
II	0.53	0.01	0.01	0.02	0.05	0.21
III	0.02	0.01	0.01	0.02	0.02	0.14
IV	0.6	0.01	0.01	0.02	0.08	0.02
V	0.05	0.01	0.01	0.02	0.08	0.02
VI	0.01	0.01	0.01	0.02	0.04	0.01
X	**0.25**	**0.01**	**0.01**	**0.02**	**0.06**	**0.10**
WHO Limit	**5.0**	**5.0**	**1.0**	**0.01**	**0.3**	**0.1**

B=Oruuwa 02; SP=Sampling period; X= Mean level; WHO= World Health Organisation

Table 26 shows the cumulative level mean of trace metals in analysed water samples from Oruuwa 02 borehole across the sampling periods. The mean levels of metal were compared to WHO standard limit. All the metal analysed were within the recommended limit for WHO expect lead (Pb). Pb is viewed as non-essential, contaminated metals with harmful health concern in human. Lead has been associated in undesirable impacts on the cardiovascular system, the Central Nervous System (CNS), as well as on the immune system. Prolong drinking of this water may cause above health-related issue due to high level of lead.

Table 27: Cumulative level mean of trace metals (mg/L) in water samples from sampling point C across the sampling periods

SP	Trace metals					
	Zn	Cd	Cu	Pb	Fe	Mn
I	0.03	<0.01	<0.01	<0.02	<0.01	<0.01
II	0.05	0.01	0.01	0.02	0.01	0.01
III	0.02	0.01	0.01	0.02	0.01	0.01
IV	0.13	0.01	0.01	0.02	0.01	0.01
V	0.02	0.01	0.01	0.02	0.01	0.01
VI	0.03	0.01	0.01	0.02	0.01	0.01
X	**0.04**	**0.01**	**0.01**	**0.02**	**0.01**	**0.01**
WHO Limit	**5.0**	**5.0**	**1.0**	**0.01**	**0.3**	**0.1**

C= Otjongombe; SP= Sampling period; X= Mean level; WHO= World Health Organisation

Table 27 shows the cumulative level mean of trace metals in analysed water samples from Otjongombe borehole across the sampling periods. Lead (Pb) was above the recommended limit for WHO limit while other traced metals were below the WHO recommended limit. The level of lead might be caused by aged pipe, faucets, and plumbing. Pb is viewed as non-essential, contaminated metals with harmful health concern in human. Lead has been associated in undesirable impacts on the cardiovascular system, the Central Nervous System (CNS), as well as on the immune system. Prolong drinking of this water may cause above health-related issue due to high level of lead.

Table 28: Cumulative level mean of trace metals (mg/L) in water samples from sampling point D across the sampling periods

SP	**Trace metals**					
	Zn	Cd	Cu	Pb	Fe	Mn
I	8.3	<0.01	<0.01	<0.02	0.06	0.26
II	6.4	0.01	0.01	0.02	0.02	0.35
III	3.3	0.01	0.01	0.02	0.03	0.27
IV	3.5	0.01	0.01	0.02	0.05	0.23
V	2.1	0.01	0.01	0.02	0.02	0.2
VI	2.77	0.01	0.01	0.02	0.02	0.15
X	**4.4**	**0.01**	**0.01**	**0.02**	**0.03**	**0.2**
WHO Limit	**5.0**	**5.0**	**1.0**	**0.01**	**0.3**	**0.1**

D= Okasongua; SP= Sampling period; X= Mean level; WHO= World Health Organisation

Table 28 shows the cumulative level mean of trace metals in analysed water samples from Okasongua borehole across the sampling periods. Lead (Pb) and manganese (Mn) were above the recommended limit for WHO standard while other traced metals were below the WHO recommended limit. The level of lead might be caused by aged pipe, faucets, and plumbing. Pb is viewed as non-essential, contaminated metals with harmful health concern in human.

Lead has been associated in undesirable impacts on the cardiovascular system, the Central Nervous System (CNS), as well as on the immune system. Manganese (Mn) in excess in water can have an increase in the risk of neurological disorder. Consuming excess manganese over a prolonged period of time can cause a Parkinson-like syndrome called manganism. Prolonged drinking of Otjongombe borehole water may cause above health-related issue due to high level of lead and manganese.

Table 29: Cumulative level mean of trace metals (mg/L) in water samples from sampling point E across the sampling periods

SP	**Trace metals**					
	Zn	Cd	Cu	Pb	Fe	Mn
I	0.4	<0.01	0.01	<0.02	0.01	0.02
II	0.23	0.01	0.01	0.02	0.02	0.03
III	0.14	0.01	0.01	0.02	0.01	0.04
IV	0.73	0.01	0.01	0.02	0.05	0.05
V	0.23	0.01	0.01	0.02	0.01	0.05
VI	0.14	0.01	0.01	0.02	0.01	0.03
X	**0.31**	**0.01**	**0.01**	**0.02**	**0.01**	**0.03**
WHO Limit	**5.0**	**5.0**	**1.0**	**0.01**	**0.3**	**0.1**

E= Okomakuara; SP=Sampling period; X= Mean level; WHO= World Health Organisation

Table 29 shows the cumulative level mean of trace metals in analysed water samples from Okomakuara borehole across the sampling periods. Lead (Pb) was above the recommended limit for WHO standard while other traced metals were below the WHO recommended limit. The level of lead might be caused by aged pipe, faucets, and plumbing. Pb is viewed as non-essential, contaminated metals with harmful health concern in human. Lead has been associated in undesirable impacts on the cardiovascular system, the Central Nervous System (CNS), as well as on the immune system. Prolonged drinking of Okomakuara borehole water may cause above health-related issue due to high level of lead.

Table 30: Cumulative level mean of trace metals (mg/L) in water samples from sampling point F across the sampling periods

SP	**Trace metals**					
	Zn	Cd	Cu	Pb	Fe	Mn
I	4.5	<0.01	0.01	<0.02	0.11	<0.01
II	0.31	0.01	0.01	0.02	0.01	0.01
III	0.21	0.01	0.01	0.02	0.02	0.01
IV	0.4	0.01	0.01	0.02	0.03	0.03
V	0.43	0.01	0.01	0.02	0.02	0.01
VI	0.35	0.01	0.01	0.02	0.8	6
X	**0.9**	**0.01**	**0.01**	**0.02**	**0.16**	**1.01**
WHO Limit	**5.0**	**5.0**	**1.0**	**0.01**	**0.3**	**0.1**

F= Okondjira; SP=Sampling period; X= Mean level; WHO= World Health Organisation

Table 30 shows the cumulative level mean of trace metals in analysed water samples from Okandjira borehole across the sampling periods. Lead (Pb) and manganese (Mn) levels were above the recommended limit for WHO standard while other traced metals were below the WHO recommended limit. The level of lead might be caused by aged pipe, faucets, and plumbing. Pb is viewed as non-essential, contaminated metals with harmful health concern in human. Lead has been associated in undesirable impacts on the cardiovascular system, the Central Nervous System (CNS), as well as on the immune system. Manganese (Mn) in excess in water can have an increase in the risk of neurological disorder. Consuming excess manganese over a prolonged period of time can cause a Parkinson-like syndrome called manganism. Prolonged drinking of Okandjira borehole water may cause above mentioned health related issue.

Table 31: Cumulative level mean of trace metals (mg/L) in water samples from sampling point G across the sampling periods

SP	**Trace metals**					
	Zn	Cd	Cu	Pb	Fe	Mn
I	0.58	<0.01	0.03	<0.02	16	0.83
II	0.69	0.01	0.01	0.02	52	10.3
III	1.02	0.01	0.02	0.02	37	8.3
IV	0.14	0.01	0.01	0.02	45	8.6
V	0.42	0.01	0.01	0.02	2.86	6.6
VI	0.11	0.01	0.01	0.02	0.8	6
X	**0.49**	**0.01**	**0.01**	**0.02**	**25.61**	**6.77**
WHO Limit	**5.0**	**5.0**	**1.0**	**0.01**	**0.3**	**0.1**

G=Ondamekondo 1; SP=Sampling period; X= Mean level; WHO= World Health Organisation

Table 31 shows the cumulative level mean of trace metals in analysed water samples from Ondamekondo 1 borehole across the sampling periods. Lead, Iron, and manganese levels were exceeding the recommended set for WHO standard while other traced metals were below the WHO recommended limit. Pb is viewed as non-essential, contaminated metals with harmful health concern in human. Lead has been associated in undesirable impacts on the cardiovascular system, the Central Nervous System (CNS), as well as on the immune system. The level of lead might be caused by aged pipe, faucets, and plumbing. Iron (Fe) occurs unsurprisingly in the underground water but levels in groundwater can be amplified by suspension of hand pump and ferrous borehole compounnd. High iron concentration in water is aesthetically undesirable; it gives rise to discolouration; it stains and taste sour. Manganese (Mn) in excess in water can have an increase in the risk of neurological disorder. Consuming excess manganese over a prolonged period of time can cause a Parkinson-like syndrome called manganism. Prolonged drinking of Ondamekondo 1 borehole water may cause above mentioned health related issue.

Table 32: Cumulative level mean of trace metals (mg/L) in water samples from sampling point H across the sampling periods

SP	**Trace metals**					
	Zn	Cd	Cu	Pb	Fe	Mn
I	1.8	<0.01	0.02	<0.02	66	84
II	0.88	0.01	0.01	0.02	50	10
III	0.95	0.01	0.01	0.02	41	7.6
IV	0.07	0.01	0.01	0.02	17.8	8.4
V	0.4	0.01	0.01	0.02	2.76	6.4
VI	0.11	0.01	0.01	0.02	1.8	6.8
X	**0.70**	**0.01**	**0.01**	**0.02**	**29.9**	**20.5**
WHO Limit	**5.0**	**5.0**	**1.0**	**0.01**	**0.3**	**0.1**

H=Ondamekondo 2; SP=Sampling period; X= Mean level; WHO= World Health Organisation

Table 32 shows the cumulative level mean of trace metals in analysed water samples from Ondamekondo 1 borehole across the sampling periods. Lead, Iron and manganese levels were beyond the recommended set for WHO standard while other traced metals were below the WHO recommended limit. Ondamekondo 2 borehole water was highly contaminated with iron (Fe) and manganese (Mn). Pb is viewed as non-essential, contaminated metals with harmful health concern in human. Lead has been associated in undesirable impacts on the cardiovascular system, the Central Nervous System (CNS), as well as on the immune system.

The level of lead might be caused by aged pipe, faucets, and plumbing. Iron (Fe) occurs unsurprisingly in the underground water but levels in groundwater can be amplified by suspension of hand pump and ferrous borehole compound. High iron concentration in water is aesthetically undesirable; it gives rise to discolouration; it stains and taste sour. Manganese (Mn) in excess in water can have an increase in the risk of neurological disorder. Consuming excess manganese over a prolonged period of time can cause a Parkinson-like syndrome called manganism. Prolonged drinking of Ondamekondo 2 borehole water may cause above mentioned health related issue.

Table 33: Cumulative level mean of trace metals (mg/L) in water samples from sampling point I across the sampling periods

SP	**Trace metals**					
	Zn	Cd	Cu	Pb	Fe	Mn
I	0.24	<0.01	0.01	<0.02	0.01	<0.01
II	0.18	0.01	0.01	0.02	0.01	0.01
III	0.13	0.01	0.01	0.02	0.02	0.01
IV	0.27	0.01	0.01	0.02	0.03	0.01
V	0.31	0.01	0.01	0.02	0.01	0.01
VI	0.16	0.01	0.01	0.02	0.01	0.01
X	**0.70**	**0.01**	**0.01**	**0.02**	**29.9**	**20.5**
WHO Limit	**5.0**	**5.0**	**1.0**	**0.01**	**0.3**	**0.1**

I=Okamuina; SP=Sampling period; X= Mean level; WHO= World Health Organisation

Table 33 shows the cumulative level mean of trace metals in analysed water samples from Okamuina borehole across the sampling periods. Lead, Iron, and manganese levels were beyond the recommended set for WHO standard while other traced metals were below the WHO recommended limit. Okamuina borehole water was highly contaminated with iron (Fe) and manganese (Mn). Pb is viewed as non-essential, contaminated metals with harmful health concern in human. Lead has been associated in undesirable impacts on the cardiovascular system, the Central Nervous System (CNS), as well as on the immune system.

The level of lead might be caused by aged pipe, faucets and plumbing. . Iron (Fe) occurs unsurprisingly in the underground water but levels in groundwater can be amplified by suspension of hand pump and ferrous borehole compounds. High iron concentration in water is aesthetically undesirable; it gives rise to discolouration; it stains and taste sour. Manganese (Mn) in excess in water can have an increase in the risk of neurological disorder. Consuming excess manganese over a prolonged period of time can cause a Parkinson-like syndrome called manganism. Prolonged drinking of Okamuina borehole water may cause above mentioned health related issue.

Table 34: Generic information extracted from the local clinic (Ovitoto) pertaining to the number of cases for water borne illness

Illness	**No of cases**		
	2019	**2020**	**2021**
Cholera	0	0	0
Diarrheal	With blood: 35 Without blood: 410	With blood: 12 Without blood: 269	With blood: 15 Without blood: 108
Typhoid	0	0	0
Hepatitis A	0	0	0
Gastroenteritis	305	201	145
Dysentery	0	0	0
Giardiasis	0	0	0
Fluorosis	0	0	0
Methemoglobinemia	0	0	0

Table 24 indicates the number of water borne illnesses recorded at Ovitoto clinic in the last three years, which might be related to unsafe drinking of water. The number of cases were analysed centred on the results of the examined water samples for microbiological parameters. The assessment generally discovered pollution of the boreholes water by microbial entities at some sampling points during the sampling tenure; though, the levels were mostly within the recommended limits. High levels above recommended standard set for *E.coli* and total coliforms were obtained. Of concern were the levels of coli form and *E. coli* recorded at Okamuina, Oruuwa 01 and Otjongombe with respect to waterborne illnesses that may develop from consumption of water. Diarrhoea is a sign of infections instigated by a host of viral, parasitic, and bacterial, organisms – most of which are transmitted by faeces-polluted water. Lack of hygiene and sanitation or safe water for drinking are common sources of diarrhoea Infection. Gastroenteritis is an illness that causes vomiting and diarrhoea. It is normally instigated by a viral bug or bacterial. It is mostly common in children, but it affects people of all ages.

Table 35: Overall mean concentration of heavy metals, EDI, HRI and CRI of groundwater from Ovitoto borehole during the sampling periods

	Zn	**Cd**	**Cu**	**Pb**	**Fe**	**Mn**
SP1	1.81	0.01	0.01	0.02	9.15	18.98
SP2	1.04	0.01	0.01	0.02	11.35	2.321
SP3	0.65	0.01	0.01	0.02	78.13	16.4
SP4	0.64	0.01	0.01	0.02	7.01	1.93
SP5	0.44	0.01	0.01	0.02	0.64	1.47
SP6	0.41	0.01	0.01	0.02	0.32	1.44
X0	0.83	0.01	0.01	0.02	17.76	7.09
WHO limit	5.0	5.0	1.0	0.01	0.3	0.1
EDI for adults	2.6×10^{-2}	3.1×10^{-4}	3.1×10^{-4}	6.2×10^{-4}	5.6×10^{-1}	2.2×10^{-1}
EDI for children	1.0×10^{-1}	1.2×10^{-3}	1.2×10^{-3}	2.4×10^{-3}	2.13×10^{0}	8.5×10^{-1}

SP = sampling periods (mean)**; X0 =** Overall mean, **EDI for Adults** = Estimated daily intake for adults, **EDI for children** = Estimated daily intake for children

Table 36: Targeted hazard quotient (THQ) results via ingestion

	Zn	**Cd**	**Cu**	**Pb**	**Fe**	**Mn**
THQ for adults	8.6×10^{-4}	6.3×10^{-4}	7.9×10^{-6}	4.5×10^{-4}	8.0×10^{-4}	9.3×10^{-3}
THQ for Children	3.3×10^{-3}	2.4×10^{-3}	3.0×10^{-5}	1.7×10^{-3}	5.0×10^{-3}	3.5×10^{-2}

THQ for adults = Targeted hazard quotient exposure dose via ingestion for adults. **THQ for children =** targeted hazard quotient exposure dose via ingestion for children.

Table 37: Carcinogenic health risk index

	Zn	**Cd**	**Cu**	**Pb**	**Fe**	**Mn**
CRI for adults	0.13	6.3×10^{-2}	-	7.3×10^{-5}	-	4.74
CRI for children	0.49	0.24	-	2.8×10^{-4}	-	18.10

CRI for adults = Carcinogenic health risk index for adults; **CRI for children =** Carcinogenic health risk index for children.

Table 38: Results of the correlation co-efficient of heavy metals in the water samples

	Zn	**Cd**	**Cu**	**Pb**	**Fe**	**Mn**
Zn	1					
Cd	0.9998	1				
Cu	0.50768	0.558	1			
Pb	0.52788	-0.4713	-0.4351	1		
Fe	0.99999	-0.4763	0.541723	-0.4532	1	
Mn	0.992	-0.835	-0.5432	0.5642	-0.4325	1

4.8 Conclusion

The results revealed that the Ovitoto borehole water at the following sampling points: Okasongua, Okandjira, Ondamekondo 1, Ondamekondo 2 and Okamuina were contaminated in terms of microbial and chemical properties. The assessment generally revealed contamination of the borehole water by Pb, Fe and Mn. However, the levels of Zn, Cd and Cu were mostly below permissible levels. Of concern are carcinogenic health risks index (CRI) outlook for Mn in both adults and children with detail to carcinogenic health impacts that may cause harm from drinking water at the above-mentioned sampling point.

CHAPTER 5: DISCUSSION

5.1 Introduction

This section discusses the results attained from the study, focusing on the study objectives. In addition, the chapter compares findings to the results of similar studies. The chapter then makes appropriate conclusions as well as recommendations for future studies.

5.2 Discussion

5.2.1 Physical Parameters

Suitability of Ovitoto boreholes water pH for potable use

Water with pH, ranging between 6.0-9.0, is considered as Grade A water, which is water of the best quality, according to NamWater standards. The pH of the boreholes water was deemed suitable for potable use because the values ranged from 6.2 to 8.8; hence, they met the WHO and NamWater standards for drinking water. The standard indicated by Edokayi (2018), also showed that the pH levels were below the standards limit for domestic use. In similar study contacted by DWAF (1996) also indicated pH level which ranged from slightly acidic to neutral throughout the sampling period. The plant growth can be affected by alkalinity or acidity of water when used for irrigation.

Suitability of Ovitoto boreholes water temperature for potable use

Temperature influences the rate of chemical and biological reactions. It is the most critical water quality indicators. Based on WHO standards limits for consumable water, cool water is considered acceptable/consumable compared to warm water because water of higher or warmer temperature promote microbial growth, simultaneously increasing taste, colour, corrosion, and odour concern (WHO, 2006). Ovitoto boreholes water was fit for human consumption in terms of its temperature, as it was below WHO and NamWater permissible limits, which is between 0-30 ºC.

Suitability of Ovitoto boreholes water turbidity for potable uses

The elevated NTU of more than 70 NTU levels were measured at all sampling sites during the six trials conducted. NamWater standards recommend turbidity of not more than 5NTU, for grade B water, which is water that is not of excellent but of acceptable quality and does not pose any health risks. WHO guidelines recommend turbidity values between 1NTU and 5NTU. The NTU levels measured at two points (Ondamekondo and Ondamekondo 2) fell under Grade D water throughout the sampling period, which is water with a great health concern or water unfit for domestic use, as they exceeded

10NTU, with Ondamekondo 2 recording the highest level of 7 480 NTU during the third sampling period (May).

This finding might have been attributed to the activities taking place, such as laundry and animals drinking at a nearby stock tank connected directly to the borehole; larger number of shrubs and weed were also observed at Ondamekondo and Ondamekondo 2, compared to other points. This might have also contributed to the turbidity levels or damage of the borehole top layer wall, which is a result of maintenance. This enabled dirt and fine particles to contaminate the water making more turbid. Ondamekondo and Ondamekondo 2 borehole water was unfit for direct domestic use; prior water treatment is vital before drinking. Full conventional treatment process is required to disinfect the water and regulate the level of turbidity to the mandatory levels for domestic use. Continuation of drinking direct borehole water can cause health conditions such as diarrhoea, nausea, cramps or even more serious conditions, as turbid water contains solid particles that can trap microbes in water.

A study conducted by Shuuya (2008) showed a great level of turbidity – greater than 3NTU – even though in the existence of free chlorine impurities. The water quality is aesthetically affected by turbidity. As the level of turbidity rises, the expanse of chlorine needed for decontamination also rises. Turbidity is instigated by suspended or colloidal materials that may come from organic or inorganic material, or the mixture of both in water, therefore preventing spread of bright through the water.

Suitability of Ovitoto boreholes water EC for potable use

EC on the other hand, had average figures ranging from 31.2-273.2 µS/cm, meaning they are within permissible limits, which stands at 150 and 300 µS/cm – as far NamWater group A and B grading is concerned. This concentration of EC in water means the water's purity is affected due to the high number of dissolved substances such as salt and heavy metals that are present in the water, resulting in production of ions that affect levels of EC (Fundamentals of Environmental Measurement, 2016).

Meride and Ayenewu (2016) reported an average EC concentration in water samples throughout the sampling period. This is strongly influenced by the concentration of TDS, meaning EC acts as an indicator for contamination by TDS, which is harmful in this case because it is above the acceptable limits (500mg/l). EC provides a sign of TDS and salinity existing in water. It plays a vital part in water quality. Hence, frequency monitoring of boreholes is essential since this indicator may gather eventually and surpass the permissible limit.

Suitability of Ovitoto boreholes water TDS levels for potable use

The results showed an increasing trend for TDS levels during the sampling period. This might be related to the rise salt concentrations, from the locality. Great concentration of saline in Ovitoto boreholes may be due to discharge of Fe from non-point sources such as disposal of metal, storm runoff and dumping sites. This could also be caused by leaching of nitrite in underground water, lower in pH and corrosion that can cause suspension of iron, therefore, rises in iron concentration in groundwater may also be because of nitrate leaching in groundwater, corrosion and decrease in pH could lead to suspension of iron thus, increases the Fe concentration in groundwater. Other possible source of rising in TDS absorption is the contamination from the locality.

Total dissolved solid is encompassed of mineral salts (mainly magnesium, calcium, sodium, potassium, chlorides bicarbonates, and sulphates) and little quantities of organic particles that are melted in water. Total dissolved solid in consumable water comes from natural materials, urban runoff, manufacturing wastewater and sewage. Based on WHO (2006), the suitability of the water with a total dissolved solid level of lower than 600mg/L is regarded to be good; consumable water yet develop importantly and gradually unsuitable at TDS levels higher than about 1000mg/l. Water with higher (exceeding 600 mg/l) total dissolved solid tastes saline and does not satisfy thirstiness, drinking of water with higher TDS could not generate adverse health problems in short period, however there is little potential of salt excess in sensitive persons in the long term (Hohls et al., 2002).

The water in the Ovitoto boreholes groundwater was unsuitable for domestic use as it was above the WHO and NamWater standard limit. The level of TDS during the sampling periods at all sampling points falls above 600mg/l which indicate poor water quality. A previous study conducted by Olajire and Imeokparia (2000) on the boreholes water quality in Nigeria a showed a level of TDS TDS ranging from 138-222mg/l and 63.8331mg/l respectively. The above-mentioned levels were lower than the ones measured in the Ovitoto boreholes.

5.2.2 Microbial entities

Suitability of Ovitoto boreholes water *E. coli* counts for potable use

During the sampling periods the summary of *E.coli* results showed an increasing trend from Oruuwa 01, which was the only sampling point where E. coli was detected during the first sampling month. An increase in the number of sampling points was detected in the second month of water sampling collection at three sampling points, namely: Okandjira, Oruuwa 01 and Oruuwa 02 (1; 1; 5 *cfu* per 100 ml). The maximum number of *E. coli* that was recorded was at Okandjira (43 *cfu* per ml) and

Otjongombe (8 *cfu* per ml) during the last sampling month – July. The E. coli count recorded for all six sampling periods were between 0-43 *cfu* per 100ml, with the lowest recording in May at Oruuwa 01 (1 *cfu* per 100 ml) and the highest in July at Okandjira (43 *cfu* per 100 ml). However, the researcher acknowledges that the microbial results for the first trial might have introduced biasness in the study because of the challenges experienced in the field, which led to late submission and analysis of the microbial results in the laboratory.

The increasing trend from the number of sampling points (where E. coli was detected) during the sampling periods might have been caused by the continuous faecal contamination from the surrounding areas – cattle grazing areas through indirect contamination, as animal faecal matter has been observed around the boreholes. Several areas along the boreholes also promotes plants (shrubs) that people use for ease – and when the wind blows, the particles might be blown into the boreholes. Other sources of pollution that might have led to the high levels of E. coli levels are animal waste, as some kraals are situated within a short distance from the boreholes. Wastes such as old plastics bags and bottles were also observed around the boreholes, and animals were also observed to be drinking from a stock tank that is connected directly from the boreholes at the same points as people.

The recorded *E. coli* levels in the Ovitoto boreholes was comparable to Edokayi (2018) study on the bacteriological and physico chemical quality of water bodies in rural area. A case study in the South African context, with E. coli levels between 0.0 and 4.9×10^3 CFU 100 mL^{-1}. All these levels were attributed to the lack of proper sanitation, faulty septic tanks leakage and pit latrine discharges in cases where the distance between latrines and water sources is short.

WHO and NamWater standards guidelines for stipulated zero presence of *E. coli* in water meant for human consumption. Based on the results, the borehole water was considered unfit for domestic use at some sampling points, namely: Oruuwa 01, Okandjira, Oruuwa 02, Okasongua and Otjongombe, as the levels constitute human health risk. The presence of *E. coli* may have worrisome effects on human health. Drinking water contaminated with *E. coli* may cause diarrhoea, nausea, vomiting, cramps, or other gastrointestinal distress – and in severe cases, the consequences can be fatal (Cobinna et al., 2015). Therefore, the water at those specific sampling points was considered suitable only for animal consumption and irrigation purposes.

Varga and Dididi (2019), in Tanzania reported that pollution of borehole water with *E. coli* in the study locality may be due to the presence of animal faecal materials around the boreholes.

Suitability of Ovitoto boreholes water coliform counts for potable use

Total coliform counts provide a sign of the unhygienic situation of a water body. Positive total coliform count is an indication of pollution in the borehole. The results showed the existence of coliforms in the water samples. Coliforms are indicator organisms that suggest that other bacteria or viruses may exist in the drinking water supply (Khan et al., 2013). Their presence meant that WHO limits have been exceeded because coliforms are expected to be completely absent in drinking water. Although NamWater allows a certain small amount of cfu/ml of general coliforms to be present in water as shown in group B (which is water still bacteriologically still fit for domestic use), the amount of general coliforms present exceeded (100 *cfu* per 100ml) the permissible limit of Group D water at Okandjira, Otjongombe and Oruuwa 02, which is water that is bacteriologically unsuitable for domestic use. This water constitute human health risk as water with high levels of coliform are likely to cause Hepatitis, gastroenteritis, dysentery, and even typhoid fever.

The existence of coliform bacteria shows that the water has been polluted with faecal matter of human or either animal (SEED, 2003). The borehole water may have been polluted by bacteria or disease-causing microbes which can occur in faecal matter. "The presence of faecal contamination is an indicator that a potential health risk exists for individuals exposed to this water. Faecal coliform bacteria may occur in ambient water because of the overflow of domestic sewage or non-point sources of human and animal waste" (SEED, 2003). This is contrarily to a study contacted by SEED on the suitability of borehole water for human consumption whereby coliforms were not noticed in the samples throughout the sampling period. This clearly indicates that the water was suitable for domestic use and may not pose health risks which are related to the existence of coliforms in water.

5.2.3. Ions

Suitability of Ovitoto boreholes water ion levels for potable use

Results from the ion levels present showed that all during the sampling periods at some sampling sites (points) had readings higher than the set permissible limits in the WHO Guideline for Drinking Water as well as the NamWater standard. Total Hardness and alkalinity were recorded to above the recommended WHO and NamWater grading criteria at the following sampling points: Oruuwa 01, Oruuwa 02, Okasongua, Ondamekondo and Ondamekondo 02. The absence of ions such as Fluoride and chloride can be caused by the lack of disinfection since the borehole water does not undergo treatment. Ions such as Calcium, Magnesium and Silicate were also above permissible limits at some sampling points during the sampling periods, that could be because they originate from rocks and the geographic location of the boreholes has rocks that could possibility be responsible for the high level of these ions.

5.2.4. Heavy metals

Suitability of Ovitoto boreholes water Heavy metals levels for potable use

The results for heavy metals concentrations were within WHO recommended standard limit for drinking water; however, the level of iron and manganese in the analysed samples at Ondamekondo and Ondamekondo 02 throughout the sampling period exceeded the permissible limit. High iron concentration in water is aesthetically undesirable, gives rise to discolouration, it is staining and taste sour. Great concentration of iron in Ovitoto boreholes groundwater can be caused due to the discharge of iron from other sources such as disposal metal, storm runoff, and dumping site. This may also be due to nitrate discharge in groundwater and corrosion, and reduction in pH might lead to suspension of Fe, consequently increasing the iron absorption in groundwater.

5.2.5 Health risk of consumption of borehole water

Zinc is occurring naturally in the globe's layer; increased levels in the surroundings have been related to man-made activities. Normally, it has been stated that heavy metals, including zinc is known to be accumulated by agricultural and plant farm produce. Therefore, potential cause of zinc in the borehole water might be due to the geographic nature of the soil. Association between the metals in water samples shown a strong association between Zn and Cd (*r= 0.99*). The THQ and CRI of Zn for adults is (8.6×10^{-4}) and 0.3, while THQ and CRI of Zn for children is (3.3×10^{-3}) and 0.49; hence, there is no harm of carcinogenic and non-carcinogenic of effect on human health from drinking water from Ovitoto boreholes as these values are <1.

Cadmium (Cd) is a poisonous metal to human beings – even though at little or low level – with no physical value (good). The endocrine and carcinogenic troublesome properties are known to be caused by cadmium, thus monitoring of cadmium is highly recommended in most human toxicological literatures. Potential pollution causes of cadmium of Cd in borehole water may be linked to human made activities such as use of fertiliser and improper use of wastes. The association between metals in water samples shown no association between Cd and Mn (*r=-0.83*) and Cd, and Cu (*r=0.55*) showed a weak correction. The THQ and CRI of Cd for adults is (6.3×10^{-4}) and (6.3×10^{-3}), while THQ and CRI of Cd for children is (2.4×10^{-3}) and 0.24; hence, there is no danger of carcinogenic and non-carcinogenic effect on human health from drinking the borehole water, as these values are < 1.

Copper is one of the metals considered vital due to the part it plays in the human physiology. Cu has been linked to the genomic syndrome known as Wilson disease at high concentration. It can occur naturally in the Globe's crust. Yet, human made activities have led to increase in Cu concentrations, which could become generally dispersed into the terrestrial and aquatic l ecosystems. The association between the metals in water samples showed no association between copper and other metals. The THQ and CRI of Cu for adults are (7.4×10^{-6}) and (-), while THQ and CRI for children are (3.0×10^{-5}) and (-); therefore, there is no harm of non-carcinogenic, since these values< 1.

Pb is viewed as non-essential, contaminated metals with harmful health concern in human. Lead has been associated in undesirable impacts on the cardiovascular system, the Central Nervous System (CNS), as well as on the immune system. Lead (lead) level were above the WHO recommended limit at all the sampling point across the sampling periods. The level of lead might be caused by aged pipe, faucets, and plumbing. Pb in borehole water is similar with those of Cu above and the metal did not indicate any association with other analysed heavy metals. The THQ and CRI of Pb for adults is (4.5×10^{-4} and (7.3×10^{-5}), while THQ and CRI of Pb for children is (1.7×10^{-3}) and (2.8×10^{-4}); hence, there is no risk of carcinogenic and non-carcinogenic effect on human health from the drinking of Ovitoto borehole water, as these values are < 1.

High iron concentration in water is aesthetically undesirable; it gives rise to discolouration; it stains and taste sour. The level of Iron was above the WHO limit across the sampling period at the following sampling points: Ondamekondo 1; Ondamekondo 2 and Okamuina. Iron (Fe) appears naturally in the underground water but the high levels in borehole water can be increased by suspension of hand pump and ferrous borehole compounds. The association between the metals in water samples showed no association between iron and other metals. The THQ and CRI of Fe for adults is (8.0×10^{-4}) and (-), while THQ and CRI for Cd for children is (5.0×10^{-3}) and (-); therefore, there is no risk of non-carcinogenic, as these values< 1.

Manganese (Mn) in excess in water can have an increase in the risk of neurological disorder. Consuming excess manganese over a prolonged period of time can cause a Parkinson-like syndrome called manganism. The level of manganese were above the WHO recommended limit across the sampling period at the following sampling point: Okasongua; Okandjira; Ondamekondo 1; Ondamekondo 2 and Okamuina. Colour/staining problems can arise when manganese concentrations exceed 0.05 mg/l. Association between the metals in water samples showed no association between manganese and other metals. The THQ and CRI of Mn for adults is (9.3×10^{-3}) and (**4.74**), while THQ and CRI of Mn for children is (3.5×10^{-2}) and (**18.10**); hence, there is no harm of non-carcinogenic effect on human health from drinking Ovitoto borehole water in both adults and children.

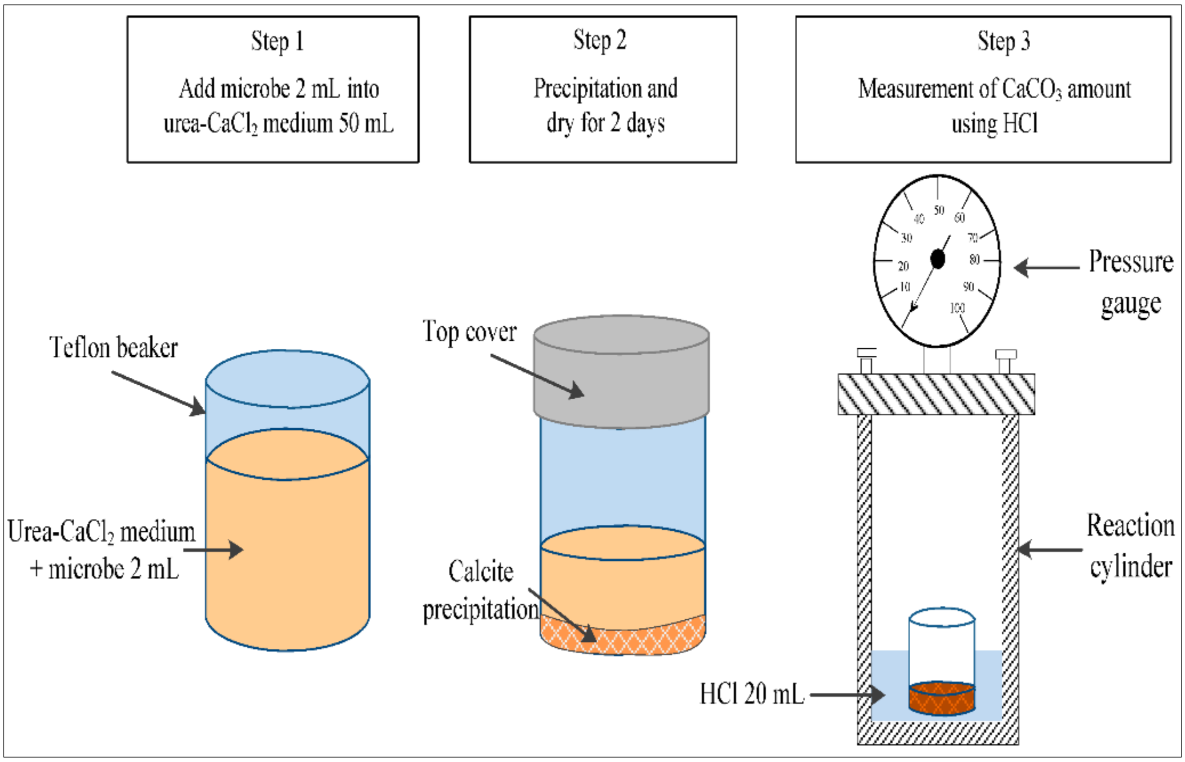
However, there is a risk of a carcinogenic effect on human health from the consumption of borehole water in both adults and children, since these values are > 1.

Figure 24: *Powdery substance suspected to be Mg/$CaCO_3$ (hand washing facility-tap)*

Figure 25: *Blockage of piped suspected to be caused by Mg/$CaCO_3$*

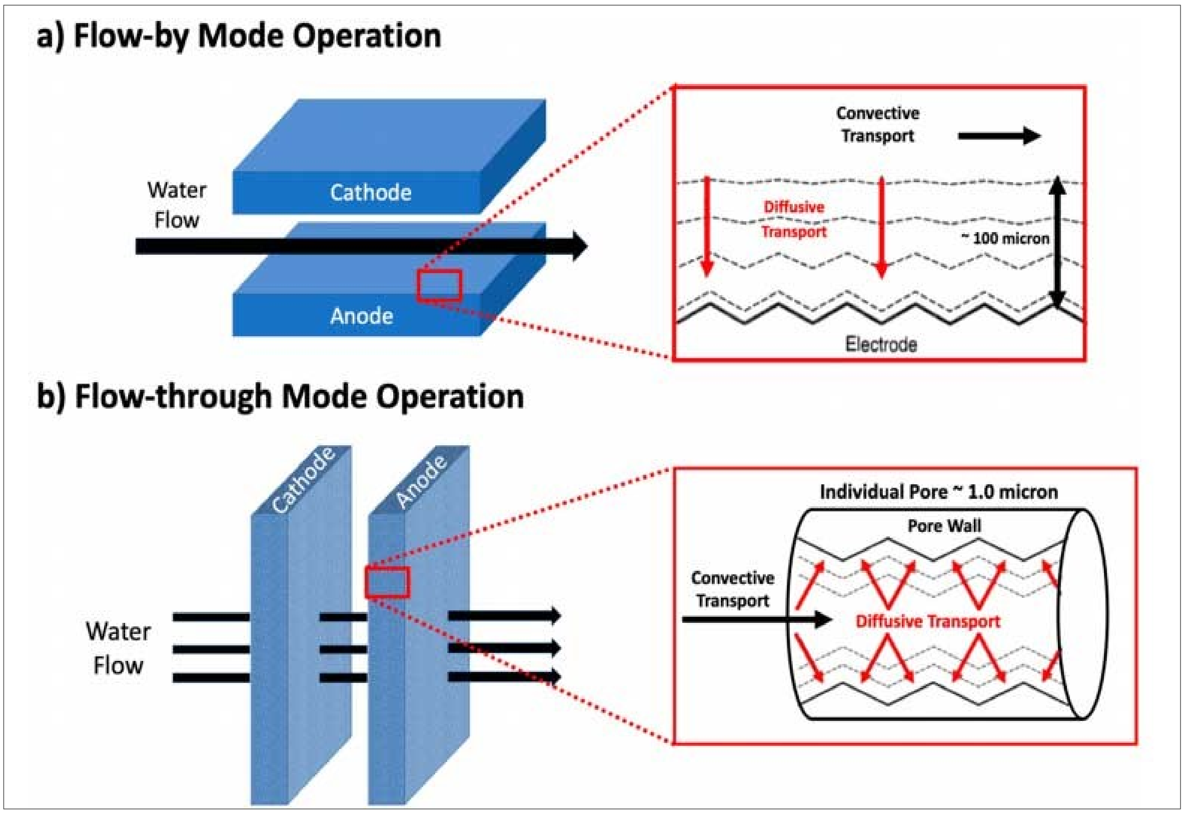
5.2.10 Chemical processes on how to remove hardness from drinking water

Electrically induced precipitation: This process use a direct electrical current to filter (precipitate) water hardness and other compounds. The electrode must be cleaned annually to remove the hardness which forms and remain on it. Kapoor (2018), indicated that the soft sludge is being formed by the precipitation on surfaces such as a washing facilities (shower rose) and heating element, and it is easily detached by fast-flowing water around the surface. The results of water hardness from the investigated boreholes in Ovitoto showed a high level of hardness. Thus, the water need to go through electrical induced precipitation to reduce the level of hardness.



Source:https://www.google.com/search?q=electrically+induced+precipitation&sxsrf=AO

Electrochemical water treatment: This system remove dissolved matters and other impurities using electricity. The technological steps go by various names: capacitive deionisation or electrically regenerated ion exchange or continuous electrolytic deionisation, (Chaplin, 2019). The system can lessen the water absorption of both positively charged pollutants such as magnesium, calcium, lead, sodium, and uranium – and negatively charged pollutants such as nitrates, chlorides, sulphates, fluorides and nitrites. The positively charged cations start to move towards the negative electrode once the negatively charged electrode or cathodes are introduced into the water. These processes use this material by merging the cathodes with ion exchange membranes made from ion exchange resins. Ion exchange membranes only permit dissolved pollutants to pass, not like other types of membranes. Any melted pollutant that is ionised is abridged in its absorption in the water. These processes have been revealed to be good at treating water to less than 5 jots per gallon of solidity (hardness), but they have trouble in achieving soft water with less than 1 grain per gallon of solidity (hardness). Inside the resin tank of salt-based water softeners, an ion exchange occurs, dropping the mineral count whereas aggregating the whole salt content of the water (Chaplin, 2019).



Source: https://www.google.com/search?q=Electrochemical+water+treatment&sxsrf=AOaemvJKLZofsMzOG

CHAPTER 6: CONCLUSION AND RECOMENDATION

6.1. Conclusion

The study revealed that water was unfit for human consumption without treatment at the following sampling points: Okasongua; Okandjira; Ondamekondo 1; Ondamekondo 2 and Okamuina. This was due to the level of the most traced heavy metal above the recommend WHO limit. Community members use the borehole water for chores such as cooking, laundry, bathing, and drinking. In terms of chemical entities, it is unfit for residents around Ovitoto within the locality of Okasongua; Okandjira; Ondamekondo 1; Ondamekondo 2 and Okamuina to use the boreholes water for human consumption without disinfection. Rises in the natural levels of heavy metals have been extensively related to human made activities. Metals may find their way into the underground through waste deposition, atmospheric dispersal, and erosional runoff. Water-soil-plant-human transfer chain of heavy metals may be caused by the accumulation and uptake of heavy metals by plants and agricultural farm produce. The assessment showed pollution of the boreholes water by the Pb, Mn and Fe; however, the levels of Cd, Zn and Cd were mostly below permissible levels. Again, the levels of microbial entities were very high at the above-mentioned sampling point. Of concern are carcinogenic health risks index (CRI) outlook for Mn in both adults and children in relation to carcinogenic health impacts that may arise from drinking of the Ovitoto borehole water at the above-mentioned sampling point. The community members of Ovitoto depend on borehole water for human consumption. The study recommends that the analysis of concerned heavy metals of Ovitoto boreholes must be included in the quality assurance at local and national level (Water utility institutions). Lastly, the results indicated that sufficient health education is not provided to the community members pertaining to safe handling of water. Hygiene and Health and education are highly recommended for people in rural settlements because of lack of proper water handling practices and sanitation. However, water was considered suitable for human consumption at the sampling points: Oruuwa 01; Oruuwa 02; Otjongombe and Okomakuara.

6.2. Recommendations

Putting research findings into consideration, the researcher came up with the following recommendations that might help communities to have access to clean water.

- Ministry of Agriculture, Water and Land Reform should prioritise water pollution control or monitoring of the boreholes, as there are regulations in place however they are not being enforced.
- Department of Water Affairs (Hydrologist) in the Ministry of Agriculture, Water and Land Reform and Namibia Water Cooperation should place in order for the maintenance of the boreholes. This was noted down as most of the boreholes were never maintain as from the date of installation.
- Environmental Health Practitioner/Public Health Specialists should strengthen the distribution of water purification tablets and enhance community health education on water prevention and control. As well as emphasis on the prevention measures of waterborne illness.
- Ministry of Education, Art and Culture must make an urgent provision and installation of filters at school water system to control the level of hardness in the water.

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Annexure

1. Observations

This checklist will be used as an observation tool at the borehole and the number of scores will determine the contamination risk.

Checklist questions	Yes	No	Comment
Are there any human activities taking around the place? (Washing, etc.)			
Are there any risks of runoffs into the borehole?			
Does the wall of the borehole have cracks?			
Does the borehole have any, visible contaminants? (plants, dirt, excreta)			
Are there any animals faecal around the borehole?			
Is the overall hygiene of the borehole and surroundings good?			
Are there any other factors that might be a source of contamination to the borehole water?			
Do the members of the communities know how to treat their water properly?			
Is the borehole used for its intended purpose?			

Total number of Yes answers= contamination risk score

8-9 = very high

6-7 = high

4-5 = intermidiate

0-3 = low

2. Interview Guide

Name of Organisation

Name of interviewer:

Name of interviewee:

Good afternoon, my name is Priskila Shevamwaveke Mwatukange, a Master of Health Science student at Namibia University of Science and Technology. I am currently busy with a research as partial fulfilment in obtaining a Master degree; the research is to assess groundwater quality and its human health risks in Ovitoto, Otjozondjupa region, Namibia.

I would like to ask you a few questions concerning the borehole and supply of water in this area. The information you provide will be kept confidential and only used for academic purposes. If there is anything you donot understand please do ask questions. Before I start with the questions I would like to get your permission to record, as it is much easier to go back in case I miss out on any vital information.

Member of the community

1. **Where do you get your drinking water from?**

…….

2. **What activities do you do/carry out at the borehole, and how often do you carry them out?**

……

3. **Where there any cases of diarrhoea after using the borehole water? Explain**

…….

4. **If yes, who did you report it to?**

……

5. **Why do some community members resort to the utilization of borehole water for domestic purposes…**………

   ……

6. **Have you received health education, and training on water treatment, and from who?**

   ……

   ………..

Existing guidelines/standards relevant to the researcher

Table 39: NamWater grading criteria for drinking water quality

Group A	Water with an excellent quality
Group B	Water with acceptable quality
Group C	Water with low health risk
Group D	Water with a high health risk, or water unsuitable for human consumption

Source: http://www.envirod.com/enviro_admin/assets/documents/p1946kkpio1d221aklron1rt711d0d.pdf (20 August 2021)

Table 40: NamWater guidelines for physio-chemical parameters

Determinants	**Unit of measurement**	**Limits for group**			
		A	B	C	D
EC	µS/cm	150	300	400	400
Turbidity	NTU	1	5	10	10
CL (Free)	mg/l Cl	0.1- 5.0	0.1 – 5.0	0.1 – 5.0	5.0
Temperature	°C	N/A			
pH	pH unit	6.0 – 9.0	5.5 – 9.5	4.0 –11.0	4.0 –11.0
TDS	Mg/l	N/A			

Source: http://www.envirod.com/enviro_admin/assets/documents/p1946kkpio1d221aklron1rt711d0d.pdf (20 August 2021)

Table 41: NamWater guidelines for physio-chemical parameters

Determinants	Limits for group			
	A	B	C	D
Standard plate counts per 1 ml	150	300	400	400
Total coliforms counts per 100 ml	0	10	100	100
Faecal coliforms counts per 100 ml	0	5	50	50
E. coli counts per 100 ml	0	0	10	10

Source: http://www.envirod.com/enviro_admin/assets/documents/p1946kkpio1d221aklron1rt711d0d.pdf (21 August 2021)

Table 42: EPA guidelines on drinking water TDS parameter

Determinant	Unit for measurements	Permissible limit
TDS	Mg/L	500

Source: https://www.epa.gov/sites/production/files/2018-03/documents/dwtable2018.pdf (21 August 2021)

Table 43: WHO guidelines for drinking water temperature

Determinant	Unit for measurements	Permissible limit
Temperature	°C	25

Source: https://www.epd.gov.hk/eia/register/report/eiareport/eia_2242014/EIA/app/app02.02.pdf (21 August 2021)

Table 44: NamWater grading criteria for bacteriological quality of drinking water quality

Group A	Water which is bacteriological very safe
Group B	Water which is bacteriological still suitable for human consumption
Group C	Water which is bacteriological risk for human consumption, which requires immediate action for rectification
Group D	Water, which is bacteriological unsuitable for human consumption

Source: http://www.envirod.com/enviro_admin/assets/documents/p1946kkpio1d221aklron1rt711d0d.pdf (21 August 2021)

Table 45: WHO Drinking Water Standard

PARAMETER	**UNIT**	**LIMIT**
Aluminium	mg Al/l	0.2
Arsenic	mg As/l	0.05
Barium	mg Ba/l	0.05
Beryllium	µg Be/l	0.2
Cadmium	µg Cd/l	5.0
Calcium	mg Ca/l	200.0
Chromium	mg Cr/l	0.05
Copper	mg Cu/l	1.O
Iron Total	mg Fe/l	0.3
Lead	mg Pb/l	0.01
Magnesium	mg Mg/l	150.0

Manganese	mg Mn/l	0.1
Mercury	µg Hg/l	1.0
Selenium	mg Se/l	0.01
Sodium	mg Na/l	200
Zinc	mg Zn/l	5.0
Chlorides	mg Cl/l	250.0
Cyanide	mg Cn/l	0.1
Fluorides	mg F/l	1.5
Nitrates	mg NO_3/l	10.0
Nitrites	mg NO_2/l	-
Sulphates	mg SO_4/l	400.0
Sulphides	mg H_2S/l	0
TOTAL "drins"	µg /l	0.03
TOTAL "DDT"	µg /l	1.0
Hydrocarbons	mg/l	0.1
Anionic Detergents	mg/l	0
Ph	N/A	9.2
Total dissolved solids	mg/l	1500
Total hardness	mg/l	500
Alkalinity	mg/l	500
MICROBIOLOGICAL PARAMETERS		
Total Bacteria	Count/ml	100
Coliform	Count/100ml	0
E. Coli	Count/100ml	0
Salmonella	Count/100ml	0
Shigella	Count/100ml	0

µg = microgram or ppb

mg = milligram or ppm

Results from the interview contacted

Three people from three entities where interviewed based on the utilization of groundwater in the area (Ovitoto).

Name of organisation: Otjozondjupa Regional Council, Okandjila settlement

Member of the community (Council's office)

1. **"Where do you obtain your drinking water from**"

-The water is coming from the reservoir being pumped from the boreholes. This pipe water is only applicable to Okandjila Township but other communities under Ovitoto resort to borehole water for domestic and agricultural purposes.

2. "What activities do you do/carry out at the borehole, and how often do you carry them out?" - No. We are provided with pipe water being pumped from the borehole to the reservoir. Thus, we have piped water.

3. "Were there any cases of diarrhoea after using the borehole water? Explain" = No

4." If yes, who did you report it to?" = No one

5." Why do some community members resort to the utilization of borehole water for domestic purposes?"

-Because they do not have access to NamWater pipeline (reservoir) so they have to opt for borehole water for domestic purposes.

6." Have you received health education, and training on water treatment, and from whom?'

-Training was not given. No health education was given.

Name of organisation: Oruua Primary School

1." Where do you obtain your drinking water from?"

-Borehole water from underground (the water is not treated)

2. "What activities do you do/ carry out at the borehole, and how often do you carry them out?"

-The water is being pumped with diesel (automation). There is a person whose job is to check the borehole water level.

3." Were there any cases of diarrhoea after using the borehole water" Explain

-Not really sure whether the diarrhoea I have experienced is caused by borehole water. But, apart from that, the borehole water causes blockage in the pipes and cause whitish.

4. "If yes, who did you report it to?" = No one.

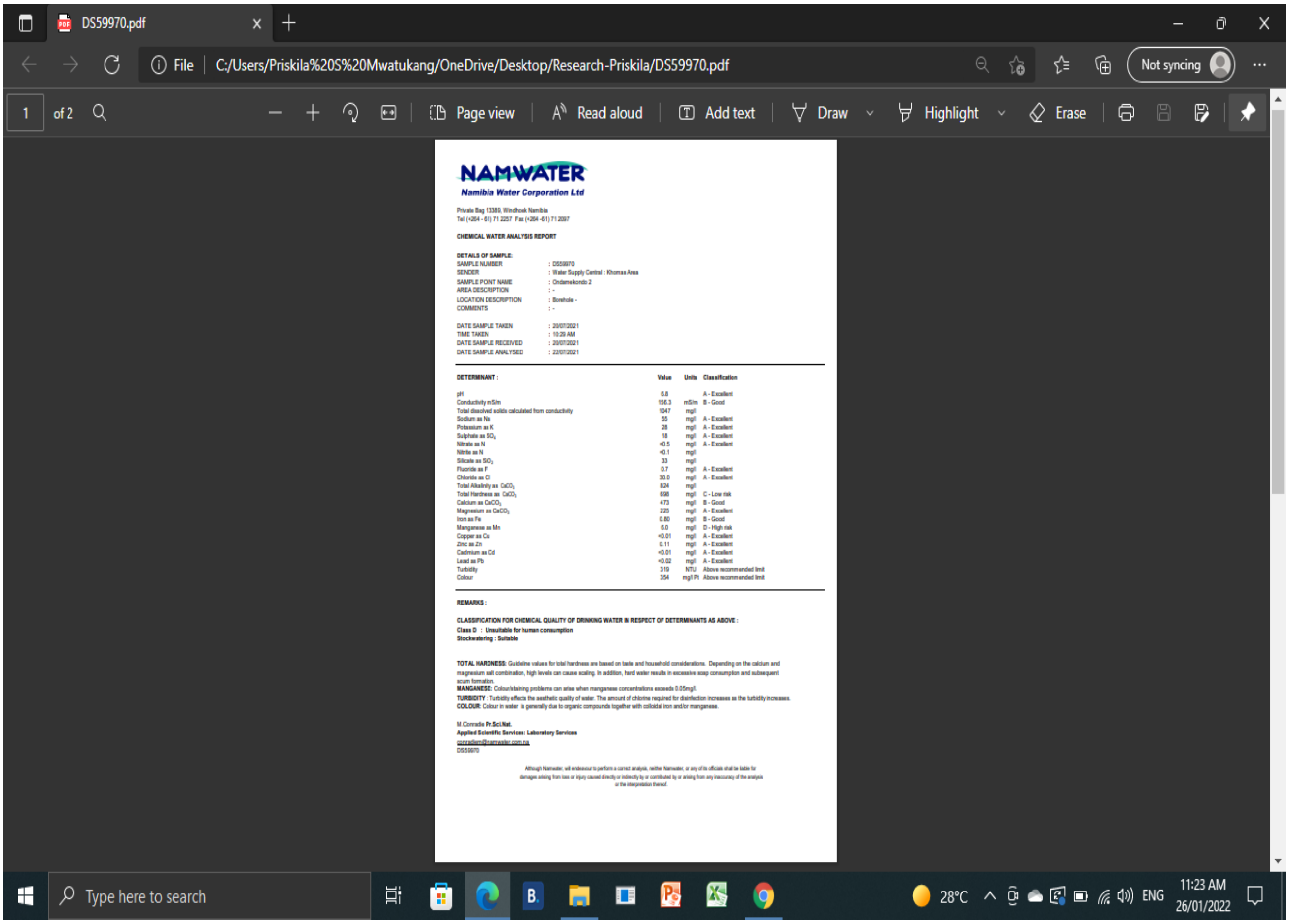
5. "Why do some community members resort to the utilization of borehole water for domestic purposes?"

-Because there is no other water apart from the borehole from the borehole.

6. "Have you received health education, and training on water treatment, and from whom?"

-No, training from given

Screenshot of the results from the laboratory and equations calculated on excel sheet



NAMWATER
Namibia Water Corporation Ltd

Private Bag 13389, Windhoek Namibia
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CHEMICAL WATER ANALYSIS REPORT

DETAILS OF SAMPLE:
SAMPLE NUMBER : DS59970
SENDER : Water Supply Central : Khomas Area
SAMPLE POINT NAME : Ondamekondo 2
AREA DESCRIPTION : -
LOCATION DESCRIPTION : Borehole -
COMMENTS : -

DATE SAMPLE TAKEN : 20/07/2021
TIME TAKEN : 10:29 AM
DATE SAMPLE RECEIVED : 20/07/2021
DATE SAMPLE ANALYSED : 22/07/2021

DETERMINANT :	Value	Units	Classification
pH	6.8		A - Excellent
Conductivity mS/m	156.3	mS/m	B - Good
Total dissolved solids calculated from conductivity	1047	mg/l	
Sodium as Na	55	mg/l	A - Excellent
Potassium as K	28	mg/l	A - Excellent
Sulphate as SO_4	18	mg/l	A - Excellent
Nitrate as N	<0.5	mg/l	A - Excellent
Nitrite as N	<0.1	mg/l	
Silicate as SiO_2	33	mg/l	
Fluoride as F	0.7	mg/l	A - Excellent
Chloride as Cl	30.0	mg/l	A - Excellent
Total Alkalinity as $CaCO_3$	824	mg/l	
Total Hardness as $CaCO_3$	698	mg/l	C - Low risk
Calcium as $CaCO_3$	473	mg/l	B - Good
Magnesium as $CaCO_3$	225	mg/l	A - Excellent
Iron as Fe	0.80	mg/l	B - Good
Manganese as Mn	6.0	mg/l	D - High risk
Copper as Cu	<0.01	mg/l	A - Excellent
Zinc as Zn	0.11	mg/l	A - Excellent
Cadmium as Cd	<0.01	mg/l	A - Excellent
Lead as Pb	<0.02	mg/l	A - Excellent
Turbidity	319	NTU	Above recommended limit
Colour	354	mg/l Pt	Above recommended limit

REMARKS :

CLASSIFICATION FOR CHEMICAL QUALITY OF DRINKING WATER IN RESPECT OF DETERMINANTS AS ABOVE :
Class D : Unsuitable for human consumption
Stockwatering : Suitable

TOTAL HARDNESS: Guideline values for total hardness are based on taste and household considerations. Depending on the calcium and magnesium salt combination, high levels can cause scaling. In addition, hard water results in excessive soap consumption and subsequent scum formation.
MANGANESE: Colour/staining problems can arise when manganese concentrations exceeds 0.05mg/l.
TURBIDITY : Turbidity effects the aesthetic quality of water. The amount of chlorine required for disinfection increases as the turbidity increases.
COLOUR: Colour in water is generally due to organic compounds together with colloidal iron and/or manganese.

M.Conradie **Pr.Sci.Nat.**
Applied Scientific Services: Laboratory Services
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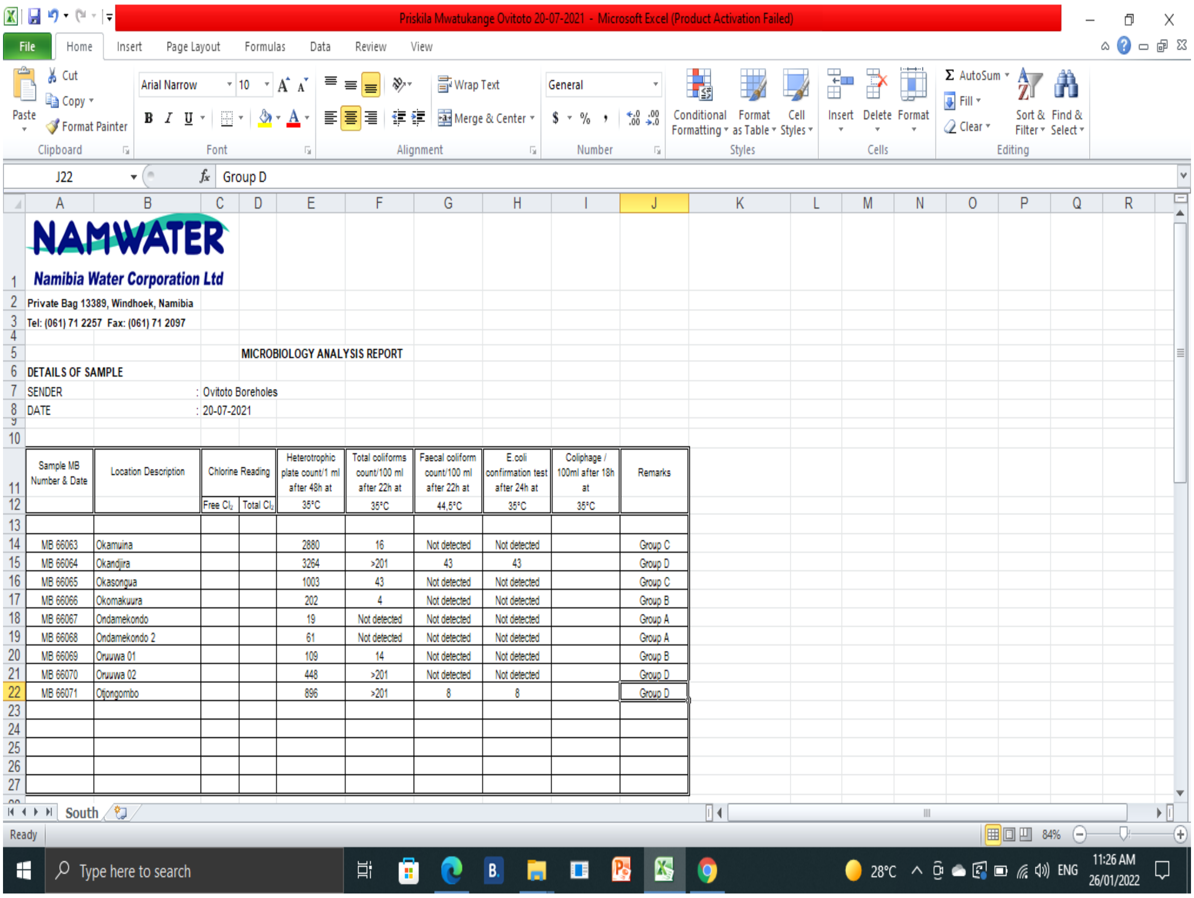
DS59970

Although Namwater, will endeavour to perform a correct analysis, neither Namwater, or any of its officials shall be liable for damages arising from loss or injury caused directly or indirectly by or contributed by or arising from any inaccuracy of the analysis or the interpretation thereof.

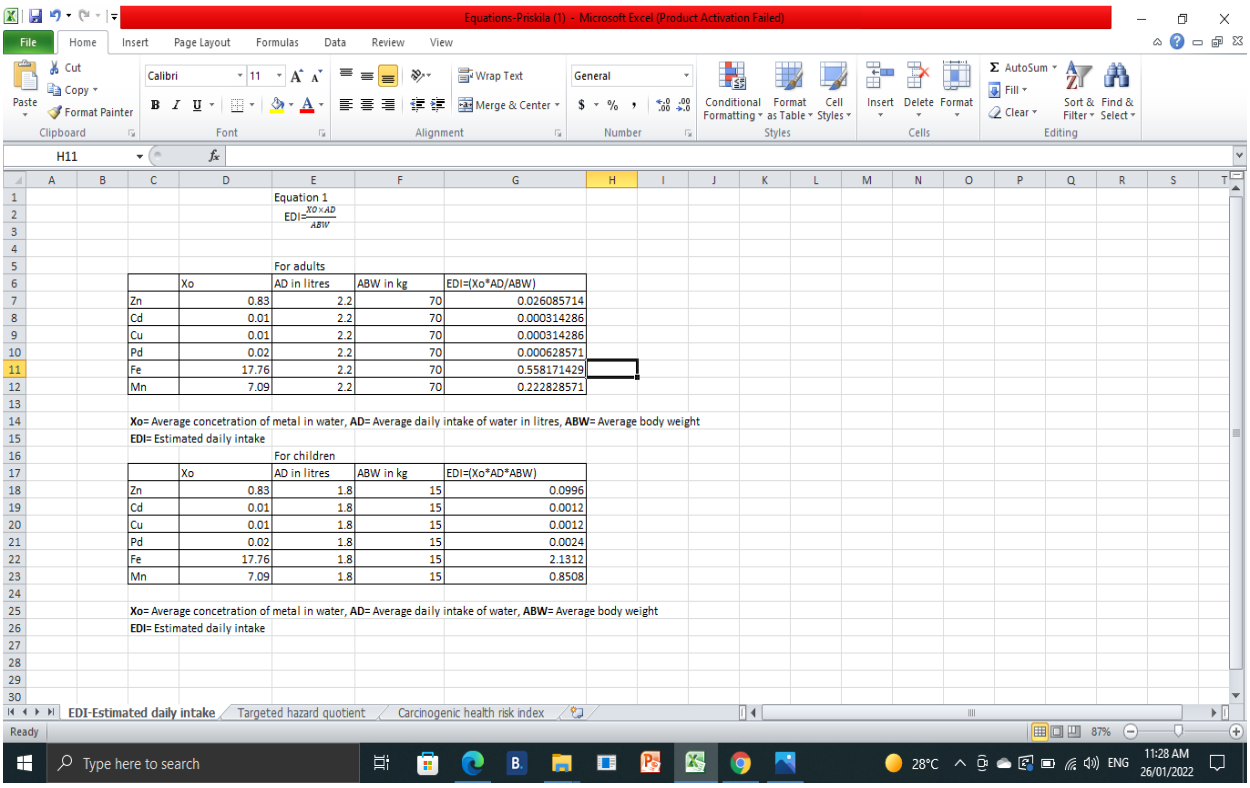


Namibia Water Corporation Ltd
Private Bag 13389, Windhoek, Namibia
Tel: (061) 71 2257 Fax: (061) 71 2097

MICROBIOLOGY ANALYSIS REPORT

DETAILS OF SAMPLE
SENDER : Ovitoto Boreholes
DATE : 20-07-2021

Sample MB Number & Date	Location Description	Chlorine Reading		Heterotrophic plate count/1 ml after 48h at	Total coliforms count/100 ml after 22h at	Faecal coliform count/100 ml after 22h at	E.coli confirmation test after 24h at	Coliphage / 100ml after 18h at	Remarks
		Free Cl_2	Total Cl_2	35°C	35°C	44,5°C	35°C	35°C	
MB 66063	Okamuina			2880	16	Not detected	Not detected		Group C
MB 66064	Okandjira			3264	>201	43	43		Group D
MB 66065	Okasongua			1003	43	Not detected	Not detected		Group C
MB 66066	Okomakuura			202	4	Not detected	Not detected		Group B
MB 66067	Ondamekondo			19	Not detected	Not detected	Not detected		Group A
MB 66068	Ondamekondo 2			61	Not detected	Not detected	Not detected		Group A
MB 66069	Oruuwa 01			109	14	Not detected	Not detected		Group B
MB 66070	Oruuwa 02			448	>201	Not detected	Not detected		Group D
MB 66071	Otjongombo			896	>201	8	8		Group D



Equation 1

$$EDI = \frac{XO \times AD}{ABW}$$

For adults

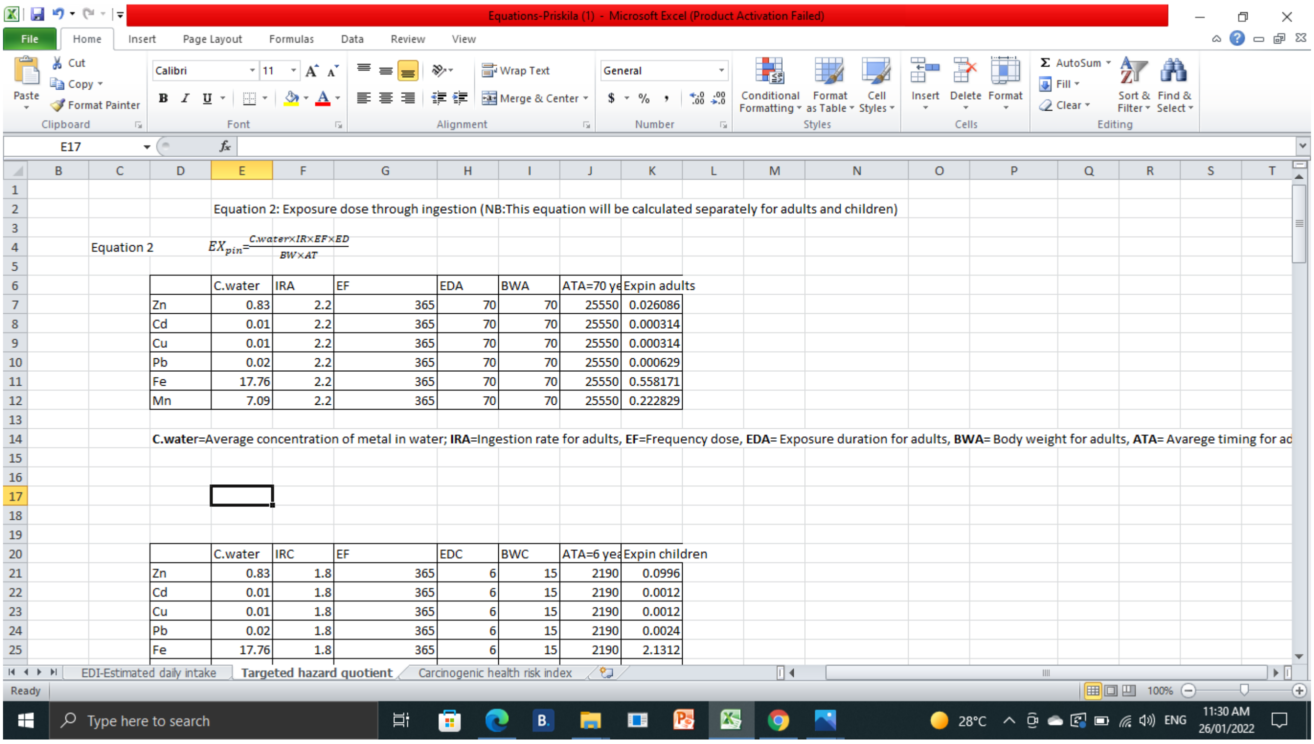
	Xo	AD in litres	ABW in kg	EDI=(Xo*AD/ABW)
Zn	0.83	2.2	70	0.026085714
Cd	0.01	2.2	70	0.000314286
Cu	0.01	2.2	70	0.000314286
Pd	0.02	2.2	70	0.000628571
Fe	17.76	2.2	70	0.558171429
Mn	7.09	2.2	70	0.222828571

Xo= Average concetration of metal in water, **AD**= Average daily intake of water in litres, **ABW**= Average body weight
EDI= Estimated daily intake

For children

	Xo	AD in litres	ABW in kg	EDI=(Xo*AD*ABW)
Zn	0.83	1.8	15	0.0996
Cd	0.01	1.8	15	0.0012
Cu	0.01	1.8	15	0.0012
Pd	0.02	1.8	15	0.0024
Fe	17.76	1.8	15	2.1312
Mn	7.09	1.8	15	0.8508

Xo= Average concetration of metal in water, **AD**= Average daily intake of water, **ABW**= Average body weight
EDI= Estimated daily intake



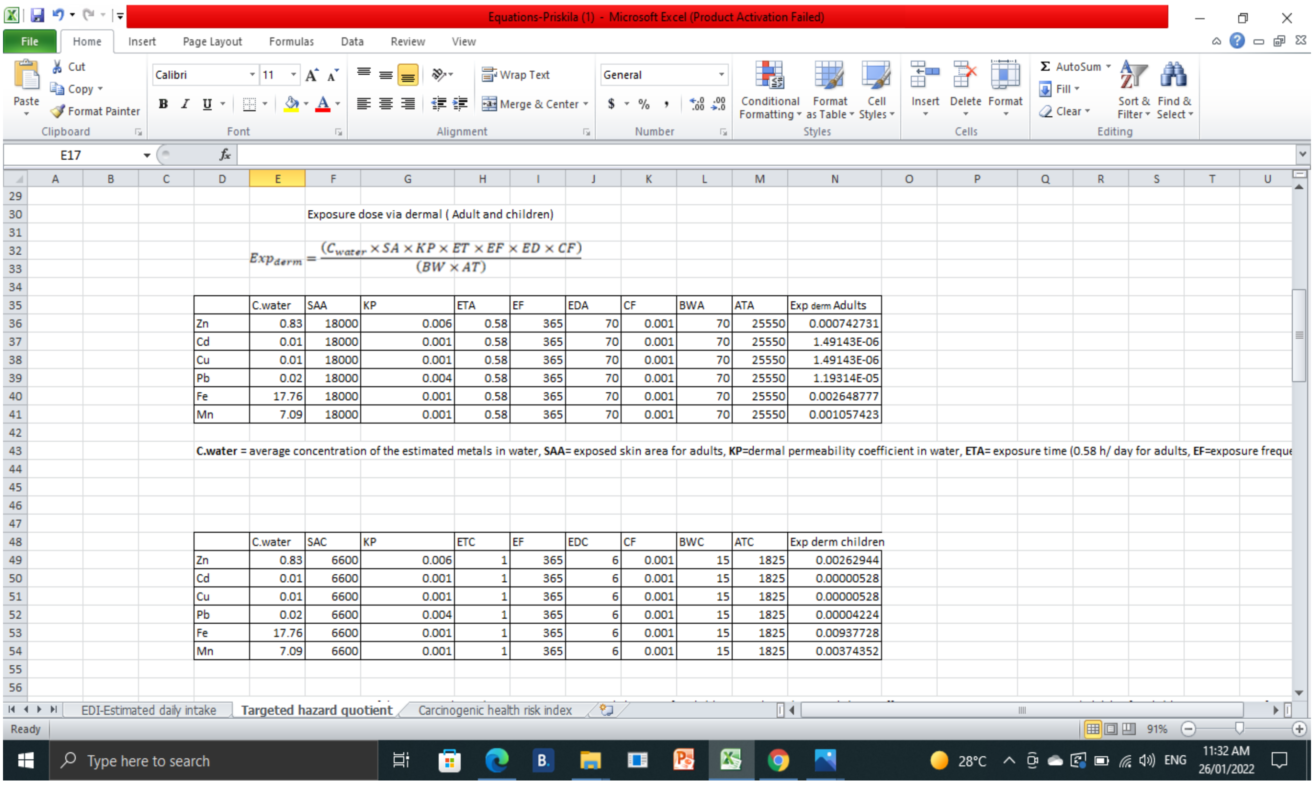
Equation 2: Exposure dose through ingestion (NB:This equation will be calculated separately for adults and children)

Equation 2 $EX_{pin}=\frac{C.water \times IR \times EF \times ED}{BW \times AT}$

	C.water	IRA	EF	EDA	BWA	ATA=70 ye	Expin adults
Zn	0.83	2.2	365	70	70	25550	0.026086
Cd	0.01	2.2	365	70	70	25550	0.000314
Cu	0.01	2.2	365	70	70	25550	0.000314
Pb	0.02	2.2	365	70	70	25550	0.000629
Fe	17.76	2.2	365	70	70	25550	0.558171
Mn	7.09	2.2	365	70	70	25550	0.222829

C.water=Average concentration of metal in water; **IRA**=Ingestion rate for adults, **EF**=Frequency dose, **EDA**= Exposure duration for adults, **BWA**= Body weight for adults, **ATA**= Avarege timing for ad

	C.water	IRC	EF	EDC	BWC	ATA=6 yea	Expin children
Zn	0.83	1.8	365	6	15	2190	0.0996
Cd	0.01	1.8	365	6	15	2190	0.0012
Cu	0.01	1.8	365	6	15	2190	0.0012
Pb	0.02	1.8	365	6	15	2190	0.0024
Fe	17.76	1.8	365	6	15	2190	2.1312



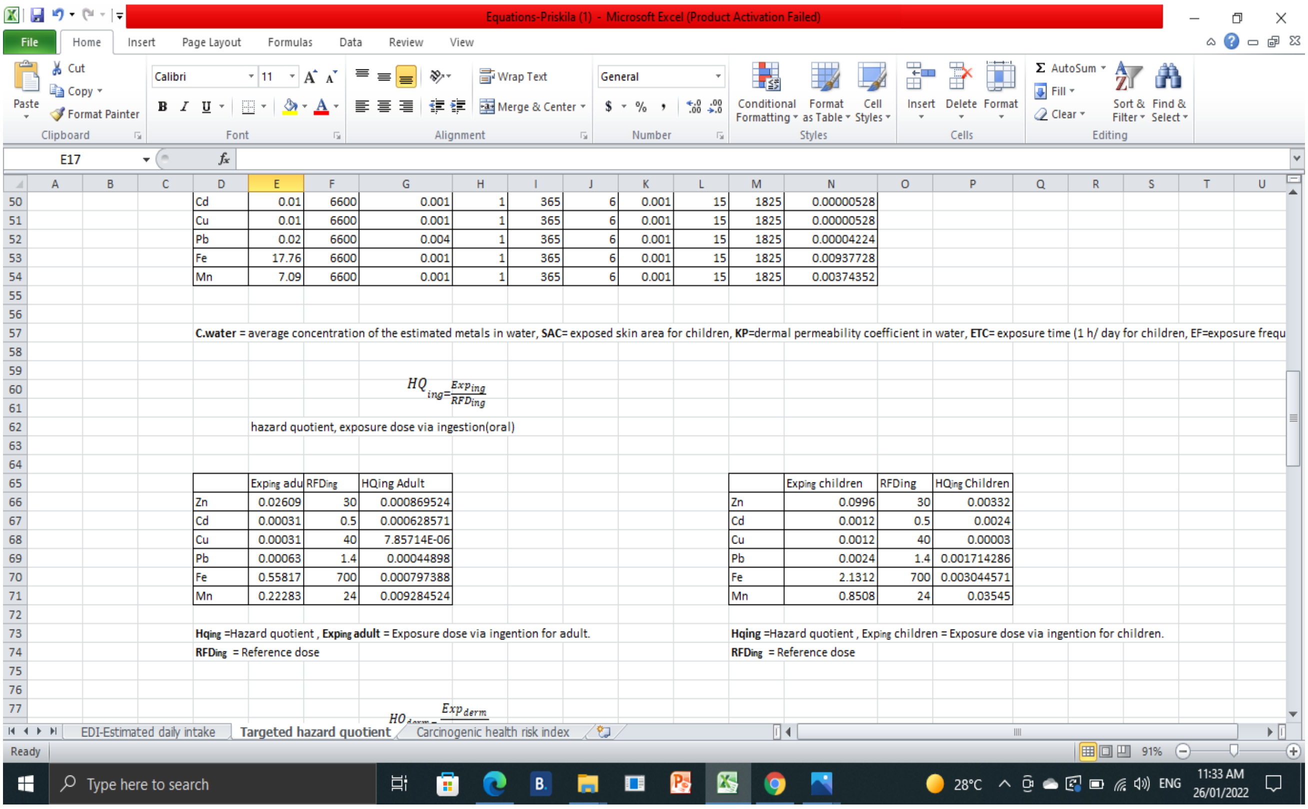
Exposure dose via dermal (Adult and children)

$$Exp_{derm} = \frac{(C_{water} \times SA \times KP \times ET \times EF \times ED \times CF)}{(BW \times AT)}$$

	C.water	SAA	KP	ETA	EF	EDA	CF	BWA	ATA	Exp derm Adults
Zn	0.83	18000	0.006	0.58	365	70	0.001	70	25550	0.000742731
Cd	0.01	18000	0.001	0.58	365	70	0.001	70	25550	1.49143E-06
Cu	0.01	18000	0.001	0.58	365	70	0.001	70	25550	1.49143E-06
Pb	0.02	18000	0.004	0.58	365	70	0.001	70	25550	1.19314E-05
Fe	17.76	18000	0.001	0.58	365	70	0.001	70	25550	0.002648777
Mn	7.09	18000	0.001	0.58	365	70	0.001	70	25550	0.001057423

C.water = average concentration of the estimated metals in water, **SAA**= exposed skin area for adults, **KP**=dermal permeability coefficient in water, **ETA**= exposure time (0.58 h/ day for adults, **EF**=exposure freque

	C.water	SAC	KP	ETC	EF	EDC	CF	BWC	ATC	Exp derm children
Zn	0.83	6600	0.006	1	365	6	0.001	15	1825	0.00262944
Cd	0.01	6600	0.001	1	365	6	0.001	15	1825	0.00000528
Cu	0.01	6600	0.001	1	365	6	0.001	15	1825	0.00000528
Pb	0.02	6600	0.004	1	365	6	0.001	15	1825	0.00004224
Fe	17.76	6600	0.001	1	365	6	0.001	15	1825	0.00937728
Mn	7.09	6600	0.001	1	365	6	0.001	15	1825	0.00374352



Cd	0.01	6600	0.001	1	365	6	0.001	15	1825	0.00000528
Cu	0.01	6600	0.001	1	365	6	0.001	15	1825	0.00000528
Pb	0.02	6600	0.004	1	365	6	0.001	15	1825	0.00004224
Fe	17.76	6600	0.001	1	365	6	0.001	15	1825	0.00937728
Mn	7.09	6600	0.001	1	365	6	0.001	15	1825	0.00374352

C.water = average concentration of the estimated metals in water, **SAC**= exposed skin area for children, **KP**=dermal permeability coefficient in water, **ETC**= exposure time (1 h/ day for children, EF=exposure frequ

$$HQ_{ing} = \frac{Exp_{ing}}{RFD_{ing}}$$

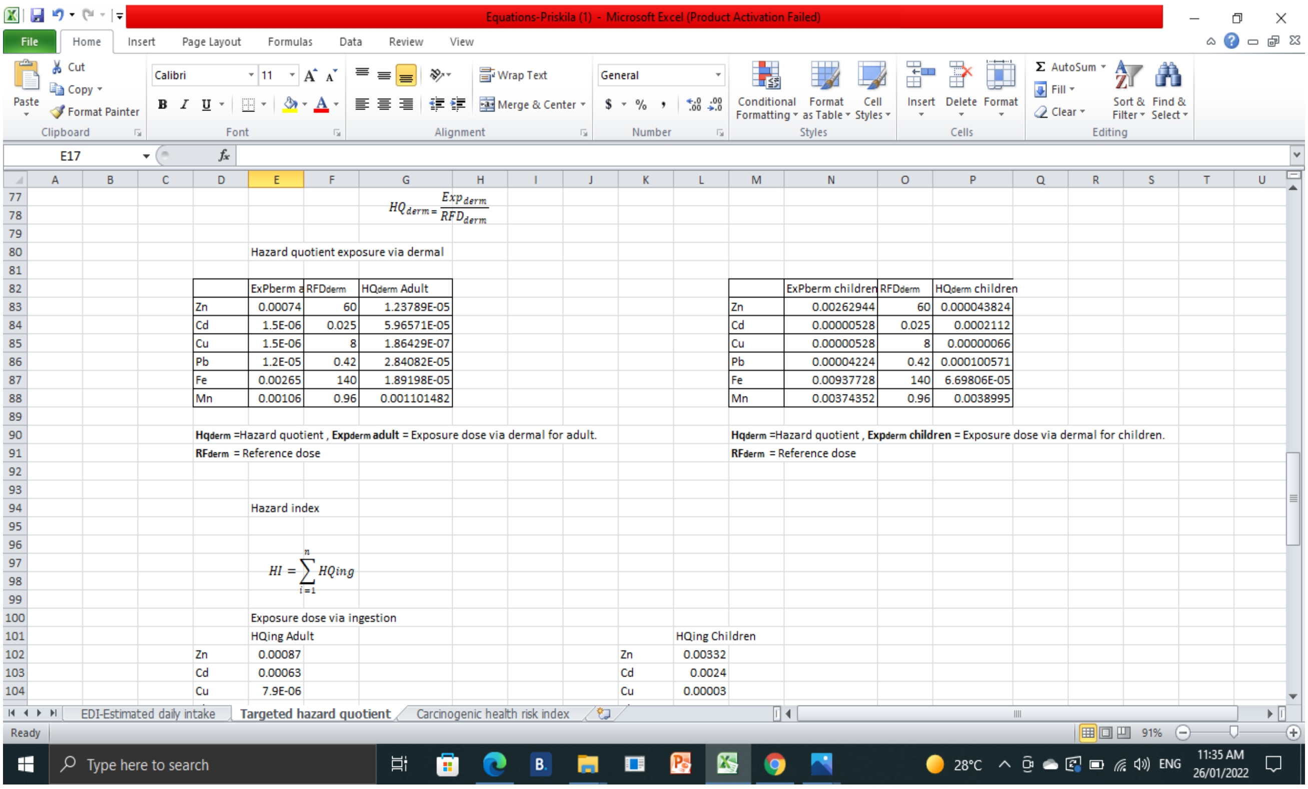
hazard quotient, exposure dose via ingestion(oral)

	Exping adu	RFDing	HQing Adult
Zn	0.02609	30	0.000869524
Cd	0.00031	0.5	0.000628571
Cu	0.00031	40	7.85714E-06
Pb	0.00063	1.4	0.00044898
Fe	0.55817	700	0.000797388
Mn	0.22283	24	0.009284524

	Exping children	RFDing	HQing Children
Zn	0.0996	30	0.00332
Cd	0.0012	0.5	0.0024
Cu	0.0012	40	0.00003
Pb	0.0024	1.4	0.001714286
Fe	2.1312	700	0.003044571
Mn	0.8508	24	0.03545

Hqing =Hazard quotient , **Exping adult** = Exposure dose via ingention for adult.
RFDing = Reference dose

Hqing =Hazard quotient , Exping children = Exposure dose via ingention for children.
RFDing = Reference dose



$$HQ_{derm} = \frac{Exp_{derm}}{RFD_{derm}}$$

Hazard quotient exposure via dermal

	ExPberm a	RFDderm	HQderm Adult
Zn	0.00074	60	1.23789E-05
Cd	1.5E-06	0.025	5.96571E-05
Cu	1.5E-06	8	1.86429E-07
Pb	1.2E-05	0.42	2.84082E-05
Fe	0.00265	140	1.89198E-05
Mn	0.00106	0.96	0.001101482

	ExPberm children	RFDderm	HQderm children
Zn	0.00262944	60	0.000043824
Cd	0.00000528	0.025	0.0002112
Cu	0.00000528	8	0.00000066
Pb	0.00004224	0.42	0.000100571
Fe	0.00937728	140	6.69806E-05
Mn	0.00374352	0.96	0.0038995

Hqderm =Hazard quotient , **Expderm adult** = Exposure dose via dermal for adult.
RFderm = Reference dose

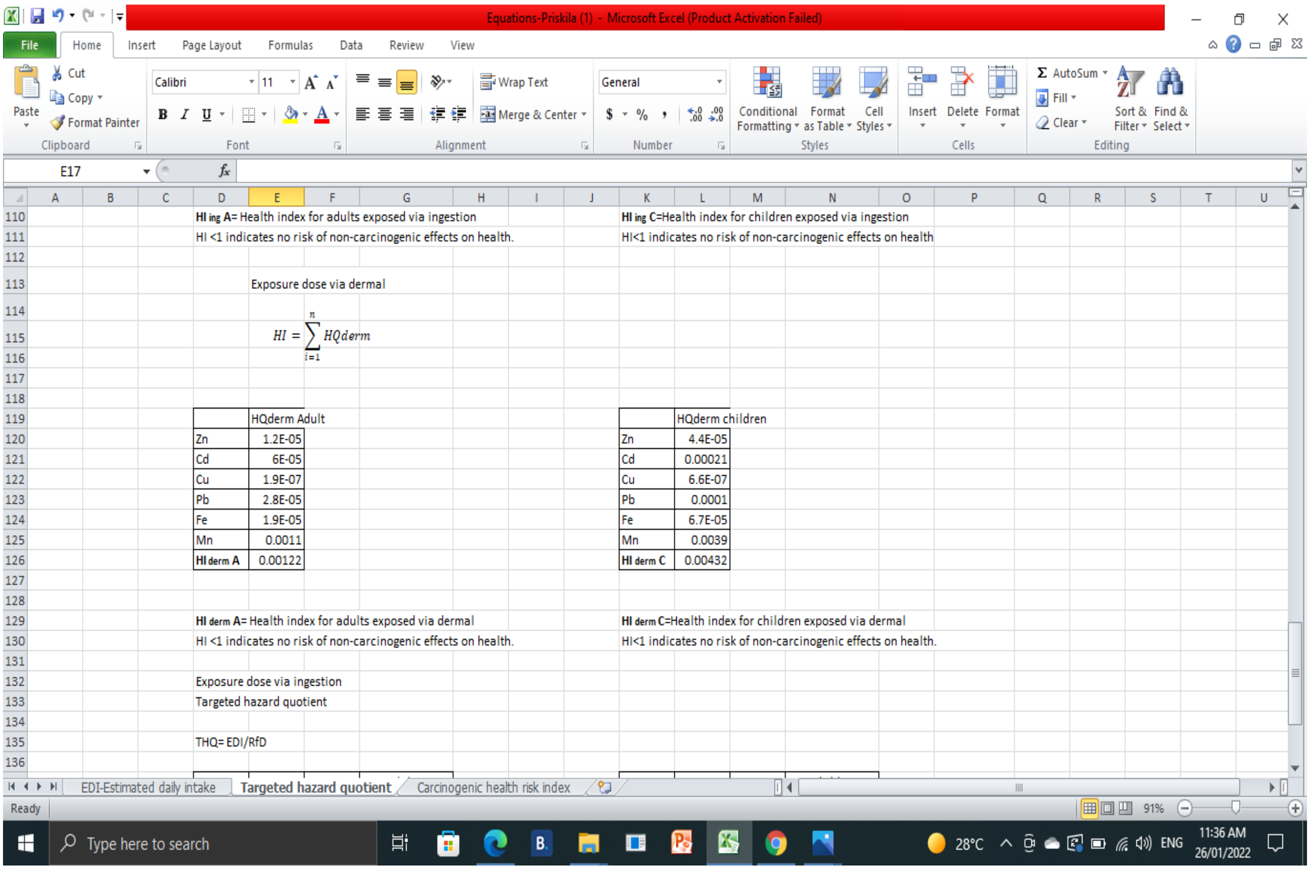
Hqderm =Hazard quotient , **Expderm children** = Exposure dose via dermal for children.
RFderm = Reference dose

Hazard index

$$HI = \sum_{i=1}^{n} HQing$$

Exposure dose via ingestion

	HQing Adult		HQing Children
Zn	0.00087	Zn	0.00332
Cd	0.00063	Cd	0.0024
Cu	7.9E-06	Cu	0.00003



Equations-Priskila (1) - Microsoft Excel (Product Activation Failed)

HI ing A= Health index for adults exposed via ingestion

HI <1 indicates no risk of non-carcinogenic effects on health.

HI ing C=Health index for children exposed via ingestion

HI<1 indicates no risk of non-carcinogenic effects on health

Exposure dose via dermal

$$HI = \sum_{i=1}^{n} HQderm$$

	HQderm Adult
Zn	1.2E-05
Cd	6E-05
Cu	1.9E-07
Pb	2.8E-05
Fe	1.9E-05
Mn	0.0011
HI derm A	0.00122

	HQderm children
Zn	4.4E-05
Cd	0.00021
Cu	6.6E-07
Pb	0.0001
Fe	6.7E-05
Mn	0.0039
HI derm C	0.00432

HI derm A= Health index for adults exposed via dermal

HI <1 indicates no risk of non-carcinogenic effects on health.

HI derm C=Health index for children exposed via dermal

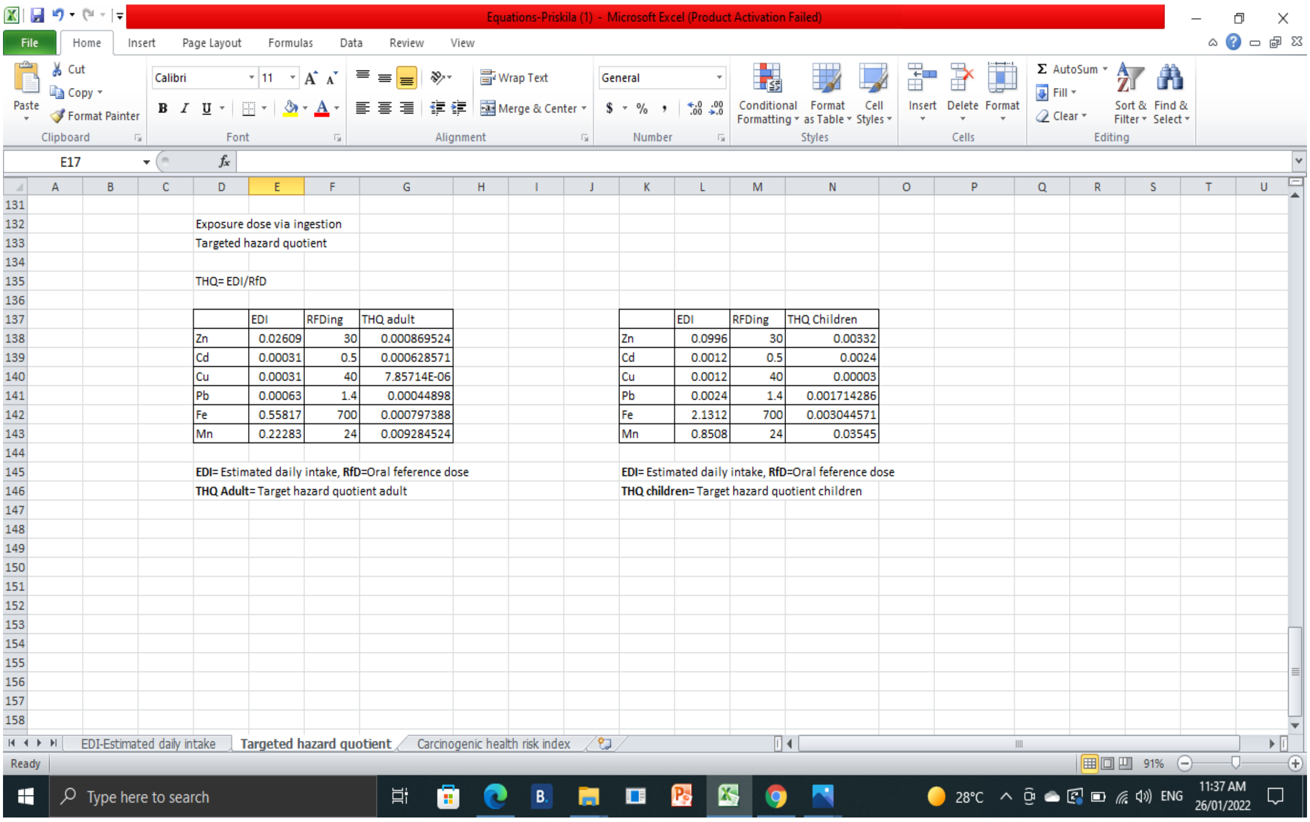
HI<1 indicates no risk of non-carcinogenic effects on health.

Exposure dose via ingestion

Targeted hazard quotient

THQ= EDI/RfD

EDI-Estimated daily intake | Targeted hazard quotient | Carcinogenic health risk index



Equations-Priskila (1) - Microsoft Excel (Product Activation Failed)

Exposure dose via ingestion

Targeted hazard quotient

THQ= EDI/RfD

	EDI	RFDing	THQ adult
Zn	0.02609	30	0.000869524
Cd	0.00031	0.5	0.000628571
Cu	0.00031	40	7.85714E-06
Pb	0.00063	1.4	0.00044898
Fe	0.55817	700	0.000797388
Mn	0.22283	24	0.009284524

	EDI	RFDing	THQ Children
Zn	0.0996	30	0.00332
Cd	0.0012	0.5	0.0024
Cu	0.0012	40	0.00003
Pb	0.0024	1.4	0.001714286
Fe	2.1312	700	0.003044571
Mn	0.8508	24	0.03545

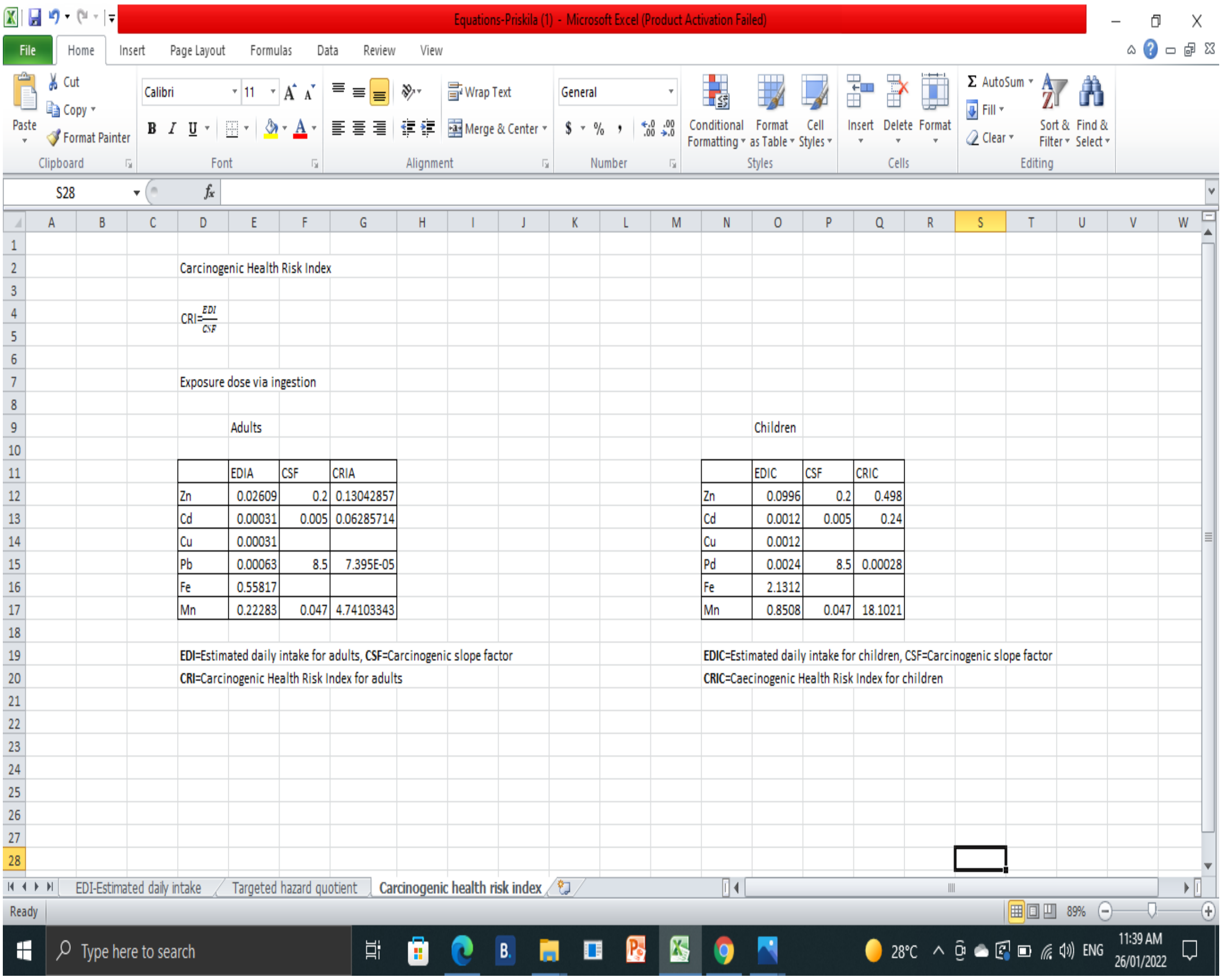
EDI= Estimated daily intake, **RfD**=Oral feference dose

THQ Adult= Target hazard quotient adult

EDI= Estimated daily intake, **RfD**=Oral feference dose

THQ children= Target hazard quotient children

EDI-Estimated daily intake | Targeted hazard quotient | Carcinogenic health risk index



Carcinogenic Health Risk Index

$CRI = \frac{EDI}{CSF}$

Exposure dose via ingestion

Adults

	EDIA	CSF	CRIA
Zn	0.02609	0.2	0.13042857
Cd	0.00031	0.005	0.06285714
Cu	0.00031		
Pb	0.00063	8.5	7.395E-05
Fe	0.55817		
Mn	0.22283	0.047	4.74103343

EDI=Estimated daily intake for adults, **CSF**=Carcinogenic slope factor
CRI=Carcinogenic Health Risk Index for adults

Children

	EDIC	CSF	CRIC
Zn	0.0996	0.2	0.498
Cd	0.0012	0.005	0.24
Cu	0.0012		
Pd	0.0024	8.5	0.00028
Fe	2.1312		
Mn	0.8508	0.047	18.1021

EDIC=Estimated daily intake for children, CSF=Carcinogenic slope factor
CRIC=Caecinogenic Health Risk Index for children