ASSESSMENT OF SELECTED BOREHOLE WATER QUALITY AND EFFICIENCY OF HOMEMADE WATER FILTER PURIFICATION DEVICES IN MARIENTAL RURAL, HARDAP REGION.

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ABSTRACT

Approximately 6.6% of Hardap Region has unsafe drinking water according to WHO (2018) guidelines. Consuming this water can cause serious illness. Three filters, namely the bucket filter, sand filter, and charcoal filters were constructed and tested for physico-chemical and bacteriological removal efficiencies. More than 500 000 people in developing countries use filters to treat drinking water. Regardless of this positive implementation, there is limited knowledge to improve its design and operation. This study reports that the filters were efficient in removing carbonate hardness, total coliforms, and *E. coli*. When statistically tested, the filters showed more or less the same removal capacity, only differing from the carbonate hardness and total coliforms content. The serial dilution tests that were conducted showed that the filters were effective at removal of total coliforms and *E. coli* at an average of 84.2% and 96.2% for the bucket filter, 91.9% and 99.6% for the sand filter and 74.9% and 98.1% for the charcoal filter respectively. However, complete removal of total coliforms and *E. coli* was not achieved. It was also reported that there was no relationship between the flow rates and the removal efficiencies. The charcoal filter had the highest removal efficiency of carbonate hardness but did not meet the daily flow rate requirement, therefore it would not be recommended. The sand filter had the highest total coliform and *E. coli* removal efficiency and it met the daily flow rate requirements, so it would be recommended, but alternative disinfection should be followed. This study recommends that filters be adjusted with smaller holes on the diffuser plates, increased filtrate depth and using granular activated charcoal. Filters should also be used with a disinfection process like boiling or chlorination.

Key words: potable water; filters; bacterial removal; chemical removal; household water treatment; water quality

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LIST OF ABBREVIATIONS

ALS	Analytic Laboratory Services
As	Arsenic
B	Bucket filter
C	Charcoal filter
CDC	Centers for Disease Control and Prevention
CFU	Colony Forming Units
DWAF	Department of Water Affairs and Forestry
E. coli	*Escherichia coli*
HWFD	Household water filter devices
IARC	International Agency for Research on Cancer
ANOVA	One Way Analysis of Variance
PCR	Polymerase chain reaction
S	Sand filter
SPSS	Statistical Package for Social Sciences
TPC	Total Plate Count
WHO	World Health Organization
UNICEF	United Nations International Children's Emergency Fund

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Dedication

This thesis is dedicated to the kind and helpful people in Hardap Region.

I sincerely hope that this thesis will, in some way, contribute to the betterment of their lives.

Declaration

I, Tiffany Claasen, hereby declare that this study is my own work and is a true reflection of my research, and that this work, or any part thereof has not been submitted for a degree at any other institution.

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CHAPTER 1

1. Introduction

1.1. Background of the study

Water quality is defined as the physical, chemical and microbiological characteristics of water in relation to natural quality, human effects and intended uses, particularly uses which may affect human health (WHO 2018 and Boyd 2015). Therefore, water quality can be defined by a range of variables which limit water use. Poor water quality has a negative impact on public health, causing various waterborne diseases like cholera, guinea worm disease and dysentery in developing countries (Taylor *et al*. 2015). Economically challenged rural communities like Hardap Region’s rural communities are still heavily dependent on unsafe groundwater as drinking water that contains high amounts of chemicals and pathogens that can cause diseases (Momba & Notshe 2003). Most of Namibia’s rural population uses water from boreholes; this groundwater rarely goes through a treatment process and contains many unwanted chemicals and organisms (Boutin *et al.* 2010). A treatment process like filtration is a process whereby solids are removed from liquid with the aid of a filter medium. It is similar to a sieve or micro-strainer that traps suspended materials between the grains of filter media. Filtration depends on a combination of complex mechanisms e.g. sedimentation, metabolic breakdown, and adsorption (Dalahmeh *et al*. 2012). The most important is adsorption, whereby particles stick onto the surface of the individual filter grains or onto the previously deposited materials. Forces that attract and hold particles to the grains are similar to those that work in coagulation and flocculation, both of which are key elements in centralized water treatment systems (Haig 2011).

Hardap Region’s groundwater does not go undergo a treatment process, therefore resulting in alarmingly high levels of nitrates and faecal indicator organisms (Boutin *et al*. 2010). Hardap is a semi-arid region of Namibia, where humans, wildlife, and livestock compete for scarce available water sources. Most of Hardap Region’s rural communities do not have improved sanitation facilities, hence resorting to the bush method (Lewis & Claasen 2016). Human faecal material together with livestock and wildlife faeces infiltrates into the groundwater source, leading to an increase of water contamination (Boutin *et al*. 2010).

There are *Escherichia coli (E. coli)* pathogroups that cause diseases in human e.g. enteropathogenic *E. coli* which causes diarrhea in children especially children 5years and younger and enterotoxigenic *E. coli*, which cause traveler’s diarrhea (Ishii & Sadowsky 2008). Due to increasing urbanization and the large number of cattle and other livestock on farms, the health risk from pathogenic *E. coli* is a major concern to drinking water quality. There is a great need to identify systems by which people in rural communities can gain access to safe drinking water because the poor microbiological quality of water impacts the health of rural communities, especially the immunocompromised people like the young children (Fawell & Niewenhuijsen 2003). These systems need to be affordable to the poorest of the rural communities, easy to operate, should be accepted culturally by the people, and the communities should continue to use them (Sobsey *et al.* 2008).

Various household water filter devices (HWFD) have been developed over the years to deal with this water contamination. Many of these devices are currently being used in various developing countries around the world as cost-effective systems for treating microbial and chemically contaminated water in order to produce drinking water of acceptable quality (Boisson *et al*. 2010) and therefore reducing the risk of water-related illness (Boisson *et al.* 2010). Variation in the effectiveness of the filters can be attributed to the technology used and local conditions (Sobsey 2002).

1.2. Statement of the problem

Approximately 6.6% of Hardap Region has unsafe drinking water according to NamWater's guidelines (Namibia Statistics Agency 2013). Consumption of the unsafe water could cause various diseases like cholera (Moyo 2018). Five percent (5%) of deaths in Namibia are due to diarrhea caused by consuming water with faecal pollution (CDC 2010). Tredoux (2004) reported that over a period of one year, 9 cases of methemoglobinemia caused by excess nitrates in water were documented in Hardap Region. Minimal efforts have been undertaken to improve the quality of unsafe water at point of consumption in Hardap Region, resulting in a lack of information regarding water quality improvements.

1.3. Objectives of the study

The main aims of this study were to assess the borehole water in Hardap Region and to observe which of the three filters could best improve the PHYSICO-chemical and biological quality of the sampled borehole water.

- To compare the physico-chemical and bacteriological water content from different boreholes in Hardap Region.
- To compare the groundwater (borehole) water results from 2011 to 2019.
- To compare the removal efficiency of physico-chemical and bacteriological water content from the biosand filter, the bucket filter and the activated charcoal filter.

- To determine if the flow rates of the three filters meet the daily human activity requirement.
- To determine if there is any relationship between the flow rates and the physico-chemical and bacteriological water content removal.

1.4. Hypotheses of the study

- H_1: There is a significant difference between the physico-chemical and bacteriological content of the water from the selected boreholes in Hardap Region
- H_1: There is a significant difference in the removal efficiency of physico-chemical and bacteriological water content from the biosand filter, the bucket filter and the activated charcoal filter.
- H_1: There is a significant difference between the flow rates of the 3 filters during the purification process of the water samples.
- H_1: There is a relationship between the flow rates and the removal efficiency.

1.5. Significance of the study

The study's results will contribute to the formulation of guidelines on water resource use and add valuable knowledge as to which filters are best suited for Hardap Region's water quality challenges. It will also provide information on the efficiency of the homemade filters as an environmentally friendly and low cost water treatment for rural communities. Rural communities can also use this information to build their own homemade water filter devices to improve their health.

1.6. Limitations of the study

- Payment was required in the form of maize meal, flour, sugar and sweets in order to get the water samples. This was a challenge during sample collection.

- More farms, areas and attributes could have been sampled if more time and funding were available.

- It proved difficult at times to gain access to information on the water quality of boreholes in Hardap Region as well as information of water filters used in Namibia.

1.7. Delimitations of study

- Only four farm’s borehole water was sampled as it is representative of the farms in the district.
- This study only focused on three filters that the rural communities could afford.
- Polymerase chain reaction (PCR) was not conducted for final identification as quantities and not species was investigated.

CHAPTER 2

2. Literature Review

2.1. Introduction to water quality

Quality should infer how well a water supply fulfills the needs of the intended user and must be evaluated on the basis of its suitability for the intended use (Liu *et al.* 2013). Water quality refers to the physical, chemical and bacteriological attributes of the water (Boyd 2015). The sanitary quality of water can be measured by total coliform presence/absence. Bacteria like coliforms are good indicator organisms to test water quality and can be shown through faecal streptococci, total coliform, fecal coliform and *E. coli* (Sirunda & Msangi, 2014). Microbiological tests for specific indicator bacteria are used to assess the quality of water and the potential public health risks from gastrointestinal waterborne pathogens (Edge *et al.* 2011).

The two magnitudes of water are closely linked, they are quantity and quality. A healthy aquatic environment is one in which the water has a lot of different communities of organisms. Water quality sustains ecological processes and many of our own uses depend on water quality that is suitable for irrigation, recreation, drinking, and fishing and to meet cultural and spiritual needs (Liu *et al.* 2013). The quality of any water system has to be maintained because if water quality is not maintained, it is not just the environment that will suffer; the commercial and recreational value of water resources will also diminish (Boyd 2015).

The availability of good quality water is a key element for human, animal and plant survival. Although the water in urban areas is repeatedly treated before human consumption, there's always the risk of accessing water that has not been treated in rural areas, which is why the water used in an area must be protected at the source (Boyd 2015).

2.2. Water statistics

The Sustainable Development Goals, goal 6 suggests that achieving worldwide access to basic sanitation services by 2030 would require doubling the current annual rate of progress (United Nations Economic and Social Council 2019). Worldwide 2.1 billion people gained access to improved water and sanitation practices, and about 946 million people are still practicing open defecation that leads to water contamination (Sibiya & Gumbo 2013). Approximately 633 million people, globally, still lack access to safe drinking water, of these people approximately 319 million live in sub-Saharan Africa (IARC 2004). About 2.4 billion do not use improved sanitation, as defined by the WHO/UNICEF Joint Monitoring Programme (IARC 2004). In 2015 it was revealed that 2.6 billion people gained access to an improved water source between 1990 and 2015. Although the number of people without an improved water source has declined considerably, about 663 million people worldwide still used unimproved sources in 2015 (United Nations Children’s Fund and World Health Organization 2015).

The United Nations World Water Development Report 3: Water in a Changing World, (WWAP 2009), indicated that 50% of malnutrition circumstances stated in Africa are related to frequent intestinal nematode infections or diarrhea infections resulting from ingesting contaminated water. In South Africa in 2011 malnutrition cases were reported as being 667 300 in total, whereby 92 000 was due to cholera, 151 000 was due to typhoid fever, 35 000 due to paratyphoid fever and 112 000 due to the hepatitis A virus (Department of Health South African Government 2019).

In rural Namibia, in 2015 the use of improved drinking water sources had increased to 87%, but there are still high levels of diarrheal-related mortality and morbidity, that can be attributed to the ingestion of contaminated water (UNICEF 2014). Associated with the efforts made to improve access to safe water, Namibia is lagging behind in the provision of adequate sanitation, like the 298 schools, throughout Namibia, that has no toilet facilities (UNICEF 2014). Over 50% of child deaths are related to lack of water, sanitation, or hygiene; 23% are due to diarrhea alone (Groundwater in Namibia 2017).

2.3. Groundwater in Namibia

Groundwater has been used for drinking purposes ever since humans settled in Namibia (Groundwater in Namibia 2017). Groundwater is a major source of water for rural communities and an integral part of our water supply (Sophocleous 2002). Although data on groundwater quality is limited, it is clear that, like other bodies of water, groundwater close to urban or industrial development is vulnerable to contamination (Boutin *et al*. 2010).

In Namibia, groundwater is distributed unevenly over the territory, thus making the construction of pipelines necessary to tap their potential (Namibia: Water Resources Management Act 2013). The coastal areas are nearly devoid of groundwater. Recharge in these areas is low and unreliable; groundwater lies at great depths and sometimes is of poor quality. Most northern areas are favorable in terms of recharge, sitting on high-yielding, very productive aquifers that contain more water than farmers and communities presently need (Namibia: National Sanitation Strategy

2010). About 45% of the water used in agriculture in the country comes from groundwater sources.

Since 1970 more than 100 000 boreholes have been drilled in Namibia. Half of these are still in operation (Groundwater in Namibia 2017). In 2012 German hydrogeologists discovered a huge aquifer in Northern Namibia called Ohangwena II, which contains about 5 billion cubic meters of water that could supply the area, where 40% of the population of the country lives (Namibia: Water Resources Management Act 2013).

In most areas in Namibia, groundwater is slightly saline (brackish), because of the little annual rainfall. In the Omusati Region that is found in the north of Namibia, four small brackish water desalination plants were installed in 2010 as part of the German-Namibian research project CuveWaters (Groundwater Desalination 2018). The plants are powered by solar energy and provide between 0.5 and 3.3 m^3 of safe drinking water per day, enough to satisfy the basic needs of between 10 and 66 people (Groundwater Desalination 2018).

In Namibian, particularly Hardap Region, rural areas rely heavily on groundwater for livestock watering points (Sophocleous 2002). The distance of a borehole to a watering point or livestock pen either increases or decreases the risk of groundwater contamination. The closer the animal pen is to the borehole, the larger the risk of contamination. The borehole could also become contaminated if it is not properly isolated at the surface, causing contaminated water to flow down into the borehole (Sasidharan *et al.* 2020). Therefore, it is utterly important that boreholes are properly sealed to prevent water from the surface from entering the groundwater source (Simataa 2010).

Namibia could not have survived this long without using its valuable groundwater resources. The dependence on groundwater is highlighted during prolonged periods of drought when surface water sources tend to dry up.

2.4. Hardap Region's water situation

Most of Hardap Region's residents rely mainly on groundwater as their primary water source, which does not go through a treatment process, putting them in a vulnerable position (Simataa 2010). There are 19 307 households in Hardap Region, of which only 39% have piped water inside their houses, 18.4% have a borehole with a tank cover, 2% have a borehole with an open tank and 6.6.% of households have unsafe water according to NamWater's standards (Namibia Statistics Agency 2011).

A study by Boutin *et al*. (2010) found that more than fifty years of poor sanitation and livestock activity have contaminated local groundwater in Hardap Region. While the government has rehabilitated some boreholes, they are not regularly maintained and the quality of the water they provide is neither monitored nor treated. Furthermore Boutin *et al*. (2010) showed that of the eight farms tested, two had acceptable water, four had water of low health risk, and two had water unfit for human consumption. Though several testing parameters were considered, these poor classifications were primarily attributed to high nitrate levels and faecal indicator bacteria. Some of the farms had high nitrate levels, e.g. 55mg/L and 75mg/L, far exceeding the NamWater's standards for safe drinking water. Furthermore, they establish no farm had water with a biological classification of grade A, meaning water being biologically safe to drink, even though it is, or it is not chemically safe to drink (Boutin *et al*. 2010).

According to Simataa (2010), livestock and community impacts were identified as one of the main causes of pollution. Elevated levels of nitrate and coliform bacteria, both of which are by-products of faecal contamination, were found to be most threatening. The lack of maintenance of infrastructure was found to be common. Financial constraints were observed as the major contributing factor to the lack of repairs. Simataa (2010) also emphasized that due to the high incidence of poverty; the majority of the farms could not afford any sanitation systems and used the bush or bucket method as a result. Faecal contamination was primarily attributed to by two sources e.g. livestock defecation in the vicinity of boreholes and human sanitation practices such as open defecation, pit latrines and use of the bucket method.

Another study by Lewis and Claasen (2018) found that the poor quality observed in Hardap region mainly arises from high levels of nitrate, Enterococci, and total coliforms. This poor water quality or groundwater contamination is largely attributed to unhygienic practices at water points and poor management of water resources. They emphasized that educational workshops and awareness programs are necessary to educate the rural area’s people on appropriate water quality monitoring and evaluation programs.

2.5. Faecal contamination in drinking water

Faecal indicator bacteria are inhabitants of the gastrointestinal tracts of humans and other warm blooded animals (Ishii & Sadowsky 2008). These indicator bacteria in general cause no harm and they are usually released into the environment with faeces and are exposed to a variety of environmental influences like sunlight, temperature, competition, and toxic industrial wastes that eventually cause their death (Stauber 2006). Large numbers of fecal indicator bacteria in the water are not harmful but may show a high risk of pathogens existence in the water (Fresno County Department of Public Health 2009). Ear infections, dysentery, typhoid fever, bacterial gastroenteritis, and hepatitis A are some waterborne diseases that coincide with fecal bacterial contamination (Ekklesia *et al.* 2015).

The presence of *E. coli* and often enterococci in water are evidence of faecal contamination from warm blooded animals. Their presence indicates the possible presence of pathogens (Mwabi *et al.* 2012). Most *E. coli* are nonpathogenic, even though there are some, such as *E. coli* O157:H7 that cause diseases in humans such as abdominal cramps, vomiting, bloody diarrhea, hemorrhagic colitis and hemolytic uremic syndrome (Stauber 2006). Healthy cattle carry pathogenic *E. coli* in their faeces. *E. coli* patho-groups that cause diseases in humans are enteropathogenic *E. coli* which causes diarrhea in infants especially children 5 years and younger mostly in developing countries and enterotoxigenic *E. coli* which causes traveler's diarrhea (Ishii & Sadowsky 2008). Enteroinvasive *E. coli* causes cell death, inflammation, and ulcers especially in children in developing countries (Weintraub 2007). Enterohemorrhagic *E. coli* primarily targets the colon and causes bloody diarrhea and enteroaggregative *E. coli* are commonly found in children in developing countries. Enteroaggregative *E. coli* cells adhere to the intestinal cells and create a biofilm causing watery and mucoid diarrhea which may last for weeks (Weintraub 2007). Due to the increasing urbanization and the large number of livestock on farms in Namibia, the health risk from *E. coli* is a major concern to drinking water quality. *E. coli* provides conclusive evidence of faecal pollution and should not be present in the water meant for human consumption (WHO 2018).

Problems usually arise when trying to determine the origin of coliform, because coliform bacteria may come from the soil, as well as from harmful faecal sources. Indicator bacteria like total coliforms, faecal coliforms, and faecal streptococci can be, but are not necessarily, associated with faecal contamination (Ishii & Sadowsky 2008). Regardless of this limitation, total coliforms are used to indicate groundwater susceptibility to faecal contamination. Faecal coliforms are used to evaluate the sanitary quality of recreational water quality standards (Heaney *et al.* 2015).

2.6. Livestock infrastructure location and their aid to water contamination

Animal faeces contain a high concentration of nutrients and pathogens (Ekklesia *et al.* 2015). Boutin *et al.* (2010) emphasize that nitrates and pathogens are the main pollutants of groundwater, which is used for consumption purposes in rural areas. Livestock in animal kraals and at watering points is the main reason for this pollution or contamination of groundwater.

Farmers use pesticides for dipping animals, and these rural farmers practice poor management of animal dipping and improper disposal of dipping fluid. The use and spillage of pesticides at such locations are of great concern. Pesticides are poisonous and carcinogenic, even a slight amount of pesticides in the water source could be a serious health risk to people who consume it (Hasani *et al.* 2011).

If livestock is spread out over a larger area or livestock densities are lower, less contamination of groundwater through contamination by animal faeces would take place, because faeces will degrade naturally over a wide area of land (Valenzuela 2009). If livestock continues to gather around water holes or in kraals, groundwater is more susceptible to contamination. A study by Sasidharan *et al.* (2020) proved that it takes about 21-317 days for water with pollutants to infiltrate the groundwater source which is about 60m deep. Urine and broken down faeces can also infiltrate into the ground water source. When urine and faeces decompose nutrients in the form of ammonia, nitrates and phosphates are produced, these nitrates bare a significant threat to groundwater (Valenzuela 2009). In areas with many livestock, hand-dug wells that tap shallow aquifers are highly vulnerable to nitrate contamination (Hasani *et al.* 2011). The risk of nitrate contamination is usually lower for boreholes that tap deeper aquifers. Farms residents with high nitrate concentrations in its drinking water can have health problems like infantile cyanosis in bottle-fed babies and health problems could also arise in cattle. Rainfall, grey water and water used for flushing purposes, can also result in this urine and faeces infiltrating into the groundwater source (Reischer 2007).

2.7. WHO guidelines for safe drinking water.

Chemical and bacteriological parameters of drinking water should not exceed a certain level (Table 2.1); otherwise it can have serious health effects on the person consuming the water (WHO 2018).

Table 2.1. Limitations of chemicals in drinking water.

Chemical	**Limit (mg/l)**
Arsenic	0.01
Cadmium	0.003
Copper	2
Lead	0.01
Fluoride	1.5

The World Health Organization (2018) water quality guidelines dictate that water is considered as a very high risk when *E. coli* most probable number (MPN) is >100/100 mL; a high risk when *E. coli* MPN ranges from >10 to 100/100 ml, an intermediate risk when the *E. coli* MPN is between 1 and 10/100 ml and a low risk when the *E.coli* MPN is <1/100 ml.

2.8. Diseases likely caused by consuming poor quality water

Poor chemical (Table 2.2) and microbiological quality of water negatively impact the health of rural communities, especially the immune-compromised people like the children and elderly (Fawell & Niewenhuijen 2003). The digestive system can be impacted, leading to diarrhea and nausea, leaving an infected person weak and dehydrated (Moyo 2018). Intestinal parasites, diarrhea, and gastrointestinal disorders are common chronic health problems and are often caused by drinking microbially contaminated water (Wolf *et al*. 2014). Globally 558 000 children aged 1−59 months were killed due to diarrhea in 2013 (Gräfe & Sparks 2006).

Table 2.2. The health implications and statistics of chemical elements in drinking water.

Elements in water	**Statistics and explanations**
Nitrate	Nitrate ions cause methemoglobinemia commonly known as Blue Baby Syndrome, a disease where the oxygen-carrying capacity of blood is reduced by nitrates (Boutin *et al*. 2010).
Fluoride	Fluoride is an inorganic pollutant, in low quantities in water it is good for dental health, in moderate quantities it causes mottling of teeth and in large quantities, it can cause bone deformities in children (Meenakshi & Maheshwari 2006).
Arsenic	Arsenic (As) contamination of groundwater (up to 5000 µg/l has been reported worldwide in over 105 countries

	(Ravenscroft 2009). It was estimated that about 200 million people, globally, are at the health risk of As poisoning due to the ingestion of As-rich water. Given the highly toxic nature of As and widespread As contamination, the World Health Organization (2018) has set an As safe limit of 10 µg/l in drinking water. Short term exposure to As contamination in water causes pigment spots in the skin and long term exposure causes Arsenicosis (Ravenscroft 2009).
Iron	In urban areas like Hardap region, it is mostly attributed to worn down and rusting infrastructure at the water source (Johri *et al*. 2010). Frequently consuming large amounts of iron can lead to iron overload; this condition is usually the result of a gene mutation. Iron overload can lead to hemochromatosis, a disease that can damage the body's organs (Ferner 2001). Symptoms of hemochromatosis include fatigue, weight loss, and joint pain, but if it is not treated, it can lead to heart disease, liver problems and diabetes (Ferner 2001).
Lead	Lead is absorbed through food and water ingestion and inhalation (Ferner 2001). Lead poisoning leads to damage to the gastrointestinal tract and urinary tract resulting in bloody urine, neurological disorder and can cause severe brain damage. Lead poisoning also causes dysfunctioning of the kidneys, reproductive systems, cardiovascular system and chronic damage to the central nervous system and peripheral nervous system

	(Ogwuebgu & Muhanga 2005).
Zinc	Excess amounts of intake can cause zinc toxicosis that leads to symptoms such as vomiting, diarrhea, bloody urine, icterus (yellow mucus membrane), liver failure, kidney failure and anemia (Proudfoot 2009).

2.9. Chemical and microbiological filter content removal

Lee (2001) and Mizuta *et al.* (2004) showed that homemade filter devices have the capacity to remove chemicals. The biosand filter is effective in removing iron, fluoride, manganese, sulfur, bacteria, viruses, waterborne parasites, algae, silt and clay (Lee, 2001). The first statement is also supported by Mwabi *et al.* (2011), where the biosand filter and the bucket filter had a fluoride removal efficiency of 99.9% and nitrate removal efficiency of 18.6% and 94.7% respectively. The biological contaminant removal performance of the biosand Filter in some countries is as follows, in Nicaragua, it removed 99.1 – 99.6% of coliform bacteria, in Canada in 1995 and in Brazil in 1998 the biosand filter removed up to 99.7% of coliform bacteria. In Vietnam, in 1998 it removed 95.8% of *E. coli* and in Bangladesh; in 1999 the biosand filter removed 99.8% of total coliforms and 99.8% of fecal coliforms (Lee 2001). The bucket filter had a high performance of *E. coli* removal because it had a sand layer with a particle size of 0.3mm and the highest flow rates in a study done by Mwabi *et al.* (2011). In Canada, in 1995 it was also reported that the biosand filter removed turbidity to up to 96.1%. In a study done by Mizuta *et al.* (2004), they concluded that activated carbon filters had higher absorptive effectiveness under the effect of temperature (10-20 ºC) than the bamboo powder charcoal filter. The biosand filter used in the Dominican Republic removed 93% *E. coli* (Stauber *et al*. 2006). Devi *et al.*

(2008) showed that homemade filter media composed of pebbles and sand removed 85.6% of fluoride in 10 h. The bucket filter in a study done by Mwabi *et al.* (2012), removed up to 99.9% bacterial pathogens. These studies have shown that these affordable household devices can result in extensive improvements in the chemical and microbial quality of drinking water (Sobsey 2002).

A study by Nikashina and Mayaosedov (1999) showed that up to 100% removal of *E. coli* and faecal coliforms can be attained with zeolites that are chemically modified with amine groups-polyhexamethylene guanidine chloride linked with epichlorohydrin. The high performance of the filters in the study was because of the fine pores of the filter media, the zeolites, the biofilm as well as the flow rates, temperature and the type of water sources. In the study, Nikashina and Mayaosedov (1999) showed that the bucket filter was the least efficient device, due to the high concentration of residual bacteria in the filtered water and it was recommended to use the bucket filter as a pretreatment filter for the other treatment devices.

It is reported that the biosand filter is able to remove more than 83% total heterotrophic bacterial populations, 99.98% of *Cryptosporidium* oocysts and 100% of *Giardia* cysts, and 50 to 90% of organic and inorganic toxicants (Palmateer *et al*. 1997).

In the study done by Mwabi *et al*. (2012), the silver-impregnated porous pot filter produced good quality water. The removal of *E. coli* by the silver-impregnated porous pot and the ceramic candle filter ranged between 95% and 100%, and 80%and 99%, respectively (Mwabi *et al.* 2012). The silver-impregnated porous pot filter was found to be the most efficient device in removing faecal coliforms and *E. coli*. The rapid sand filter produces water of poor microbiological quantity as no biological layer develops on the top surface of the sand bed to remove the pathogens (Sobsey 2002).

As turbidity is a measure of the clarity of a liquid, microorganisms attach themselves to the surface of suspended particles in this liquid. Therefore, the removal of the larger particles could result in the removal of pathogenic microorganisms (Al-Gheethi *et al.* 2018). Mwabi *et al*. (2012) showed that as the turbidity was reduced, indicator bacteria were also reduced.

2.11. Point-of-Use Water Filters in developing countries

A point-of-use treatment system is any form of water treatment used by a household within their premises (Mwabi *et al*. 2012). These point-of-use treatment systems treat moderately small volumes of water, normally only treat water for drinking and cooking purposes. The filtration process is a simple and effective method of treating drinking water, and therefore it is a suitable process to be used in point-of-use treatment systems. The filtration process does not require any addition of chemicals and can be operated without a power supply. Numerous household water treatment devices have been developed in developing countries as cost-effective systems for treating microbial contaminated water to produce water of acceptable quality (Mizuta *et al.* 2004). Studies have shown that these simple and relatively cheap household water filter methods have resulted in considerable improvements in the microbial quality of drinking water and reduce the risk of death and illness, even in the absence of improved sanitation e.g. piped toilets and washing sinks (Sobsey 2002).

In developing countries when we search for new technologies, like these filters, not only science must be considered, factors like economics and availability must also be taken into consideration (Lee 2001). The filters should not be too expensive, as most of the communities will not be able to afford them. The filters must also be widely available to the communities if parts break, it must be easily replaceable. The filters must also be easy to operate and people must understand it (Lee 2001).

2.10. General construction of filters

In filtration systems, the most commonly used filter medium is sand, though media such as crushed magnetite, garnet, coconut husks, activated carbon, ceramic candles and other natural and inert synthetic materials are also used (Barnes *et al.* 2009). The type, size, porosity, pore size and surface area of the filter media are factors determining the effectiveness of the filtration process (Mwabi *et al*. 2012). Barnes *et al.* 2009 stated that sand porosity is an important factor relative to the formation of filters. High porosity leads to high flow rates, low porosity leads to low flow rates and clogging. A moderate porosity is required for the optimal operation of the filters. Dalahmeh *et al*. (2012) emphasized that for the charcoal filter to work optimally the first layer must be gravel to remove large pieces of debris, followed by the sand layer, which removes smaller particulate matter and lastly a layer of charcoal to remove bacteria and some chemicals.

The Biosand filter holds water about 5cm above the top surface (Figure 1) of the filter media to make sure that maximum oxygen is received by the microorganisms in the biofilm (Mwabi *et al*. 2012). This water layer protects the biofilm from being disturbed by incoming water. Conversely, the top water layer cannot be too deep or oxygen will not diffuse and the microorganisms will suffocate, thus destroying the biofilm (Mwabi *et al*. 2012). A diffuser plate (Figure 2.1) can also be used to protect the biofilm layer from being disturbed (Mwabi *et al*. 2012). Adding any chemicals to the biosand filter would complicate the originally simple filtration process (Lee 2001).

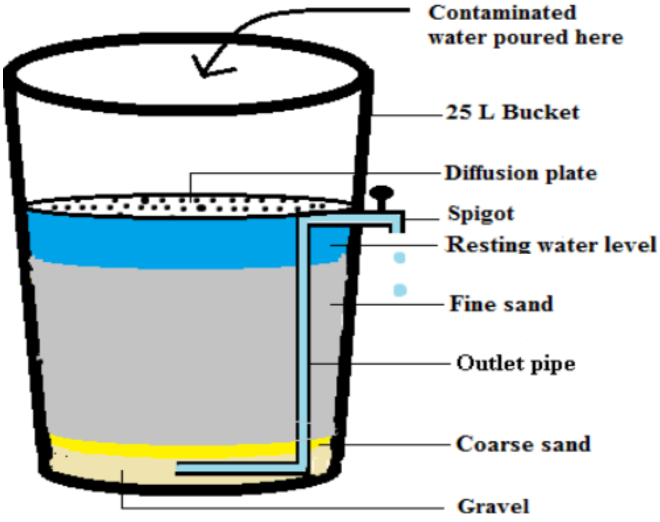

Figure 2.1. Schematic diagram of the standard biosand filter.
(Source: Mwabi *et al.* 2012)

When activated carbon in the filter is exhausted it is not as easily noticeable as the flow rate of water will remain constant even if the active carbon depleted. When the activated carbon is depleted the filter will no longer effectively adsorb undesirable chemicals, which can result in health problems for the filter's users (Stringfellow & Oh 2002). The activated carbon/charcoal filter (Figure 2.2) usually wears out after approximately 6 months of constant use (Dalahmeh *et al.* 2012)

Figure 2.2. Schematic diagram of the standard charcoal filter.
(Source: Buzzle.com)

The bucket filter (Figure 2.3) breaks down organic matter in the filter. The particles stick to grain surfaces or get caught in voids on grains or in spaces between grains (Dalahmeh *et al*. 2012). The negatively charged grain surfaces can attract positively charged unfiltered particles and bond with them through a process called adsorption. Chemical bonding also takes place as certain particles in the unfiltered water come into contact with and react with the media (Mwabi *et al*. 2011). Washed gravel or crushed rocks are placed at the bottom of the filter bed with the finer gravel on top of the coarser gravel to keep the media grains from washing into the system (Barnes 2009).

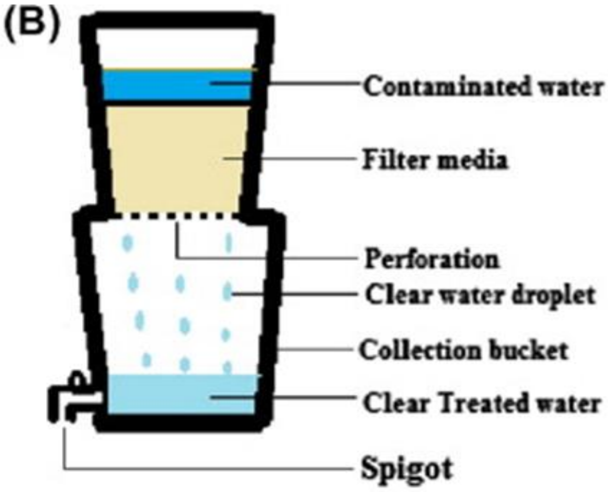

Figure 2.3. General schematic diagram of the bucket filter.

(Source: Mwabi *et al.* 2012)

2.12. Filtration Mechanisms

The physical, chemical and biological process of water treatment is known as filtration and encompasses separation of suspended solids and impurities from water by passing it through porous media (Dalahmeh *et al*. 2012). Filtration is accomplished through two types of mechanisms e.g. physical removal mechanisms and biological removal mechanisms:

2.12.1. Physical Removal Mechanisms of filters

Surface straining or Mechanical Straining

Particles that are too large to pass through the closely packed filter media are captured; this is known as either Surface straining or Mechanical Straining (Nigay *et al.* 2018). Particles in the water are removed when they are larger than the pore size of the filter media particles and so they are trapped at the surface or inside the media, removing the particles from the water. Also known as the "sieve effect which is amplified by deposit on the filters' surface of a layer made up of clay, organic matter, algae, and macro- and microorganisms" (Dalahmeh *et al*. 2012). As particles are captured by the filter media, the pore openings become smaller and surface straining is improved, allowing the capture of much smaller particles as the filter cake develops. The filter cake which is composed of living organisms and debris from the water becomes an effective filtering medium (Nigay *et al.* 2018). The filter cake is an extension of the filter bed containing the smallest pores to achieve the most effective straining (Nigay *et al.* 2018).

Sedimentation

Particles that are trapped inside the pores of the filtrate settle within the pores and are separated from water by a sedimentation process. Sedimentation is when particles in suspension settle out of the fluid in which they are carried and come to rest against a barrier, due to their motion through the fluid in response to the forces acting on them media (Dalahmeh *et al*. 2012).

Adsorption

Chemical adsorption processes remove impurities in water by taking up the molecules of the impurities by the internal or external surface of the adsorbent (filter media in this case). The impurities attach to the surface of the filter media, allowing cleaner water to pass through (Mwabi *et al*. 2012).

2.12.2. Biological Removal Mechanisms

When a biologically active layer, also called the biofilm, is formed on the top of the filter medium, organic substances are converted into less toxic compounds because of biochemical actions (Ngai *et al.* 2006). This results in the removal of harmful impurities and microbiological contaminants that may be present in the water. Even though biological activity in filters in the sand layer is not quite understood, experts have a vague understanding of the processes involved, but specific interactions are unknown (Ngai *et al.* 2006). Biological Mechanisms by which filters operate are:

Metabolic breakdown

Dalahmeh *et al*. (2012) showed that because only a small percentage of organic carbon is biodegradable, metabolic breakdown plays only a minor role in the removal of bacteria in filtration.

Bacterivory

Bacterivory is whereby predators such as rotifers and protozoa e.g. rhizopods and ciliates consume bacteria (Mwabi *et al*. 2012). There are two mechanisms by which bacterivory aid in filtration:

1. Predators graze on bacteria and detritus attached to sand grains to open up sites for prospective bacterial attachment.

2. Predators remove suspended particles (Dalahmeh *et al*. 2012).

2.13. Filter aspects

2.13.1. Filter ripening

This is to allow the biofilm in the filter to mature (Dalahmeh *et al*. 2012). Filter ripening is a complex process that encompasses both biological and physical mechanisms. As filtration progresses, biological growth consisting of algae and bacteria occurs within the filter media (Bellamy *et al*. 1985). Bellamy *et al*. (1985) determined that a new filter's sand bed will remove 85% of the coliform bacteria in the influent, but as the sand bed matures biologically, the percent removal of the coliform bacteria in the influent improves to more than 99%, showing that the filter does not effectively remove bacteria during the ripening period. The ripening period for the biosand filter is usually one to two weeks (Jellison *et al.* 2000)

2.13.2. Filter maintenance and cleaning

The maintenance of a filter system is very simple as no chemicals are added to filtered water (Jellison *et al.* 2000). The maintenance of filters is required when the rate of water flow slows down. About 2-3 cm of the fine sand layer is removed. Fine sand is then filled to the filter media. It takes approximately 2 to 3 days to reestablish its normal flow operation (Dalahmeh *et al*. 2012).

2.13.3. Diffuser Plate

The diffuser plate is a thin polyethylene plastic plate with perforations made with a 2mm hole drill (Figure 2.4). The main function of a diffuser plate is to prevent incoming water from disturbing the biofilm layer on the upper filter media (Mwabi *et al*. 2012). The diffuser plate also serves as a sieve to trap the larger impurities carried by the water e.g. rust in pipes and stones (Stauber *et al*. 2006). The measurements of the diffuser plates must be fit tightly against the inner wall of the filter, as not to let larger impurities through.

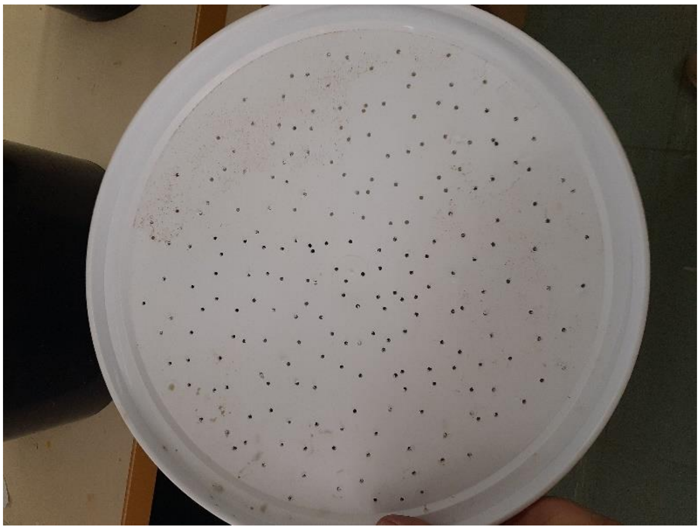

Figure 2.4. Diffuser plate made with a drill.

2.13.4. Filtration Rate

Filtration rate or flow rate is an important aspect in determining the efficiency or performance of the filter (Mwabi *et al*. 2012). People desire a filter with higher filtration rates, however higher filtration rates mean that the porosity is high with larger pore size, letting more impurities pass through the filter. The filtration rate of a filter is often inversely related to the contaminant removal performance (Dalahmeh *et al*. 2012).

CHAPTER 3

3. Research Methods

3.1. Study area

Namibia is one of the driest countries south of the Sahara. The country has an area of 824 000 km² and is divided into 14 regions (Figure 3.1), Hardap Region being the second last one to the southern border of the country. The region has an area of about 109 000 km² with a population of roughly 79 000 people (Namibia Statistics Agency 2013). Hardap Region's elevation ranges from 2 000 m to 2 200 m above sea level. It is bordered in the south by !Karas Region and in the north by Erongo, Khomas and Omaheke Regions. The region also shares a common border with Botswana and South Africa on the east and the Atlantic Ocean in the west. Hardap Region stretches the entire width of Namibia, from the western coast to the eastern border across the country.

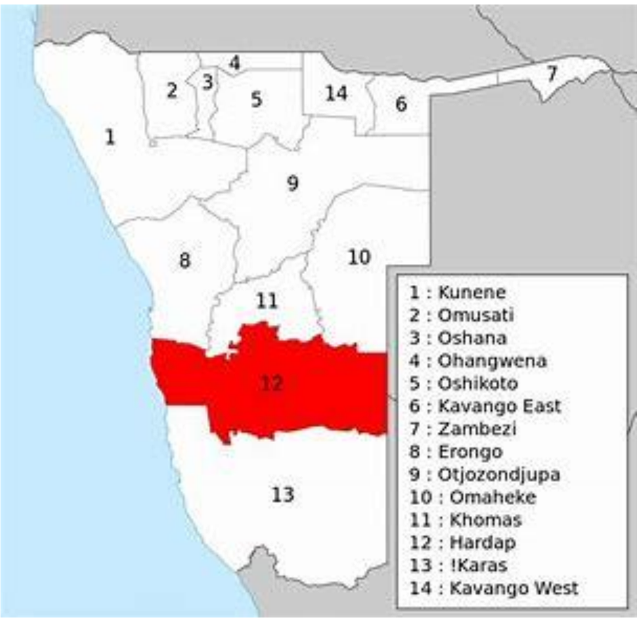

Figure 3.1. Map of Namibia highlighting the Hardap Region

(Source: id.wikipedia.org üzerinde kullanımı)

3.2. History of the farms

During the times of apartheid, the National Party of South Africa implemented the Odendaal Plan in Namibia; this was done to ethnically segregate the country. The government bought a large area of land and installed boreholes as water points. Homesteads, called Odendaal farms, were formed around these water points. A lot of these homesteads still exist today in the Hardap Region of Namibia as farms. This study will focus on four Odendaal farms. The water source on these Odendaal farms is still groundwater acquired from a borehole. A lot of these boreholes were drilled in the 1970s and some are still functional. The government has been working to restore some of these boreholes, but the geographic isolation of these farms seems to be a challenge. The Directorate of Water Supply and Sanitation Coordination (DWSSC) manages the water supply and borehole repairs, while community members or farm owners themselves finance the repairs. The primary concern on these Odendaal farms is ground water pollution, caused by open human and livestock defecation (Lewis & Claasen 2016). The most common sanitation practice by the farm workers is the bush or bucket method, whereby they defecate in the bushes or a bucket and then dump it in the bushes. The main profession of residents on the 4 Odendaal farms (Figure 3.2) is livestock farming. These sanitation practices like the bush and bucket method in combination with the abundance of livestock on these farms contribute to nitrate pollution, as livestock faeces contain an adequate amount of nitrates. These livestock faeces also increase the risk of bacterial contamination.

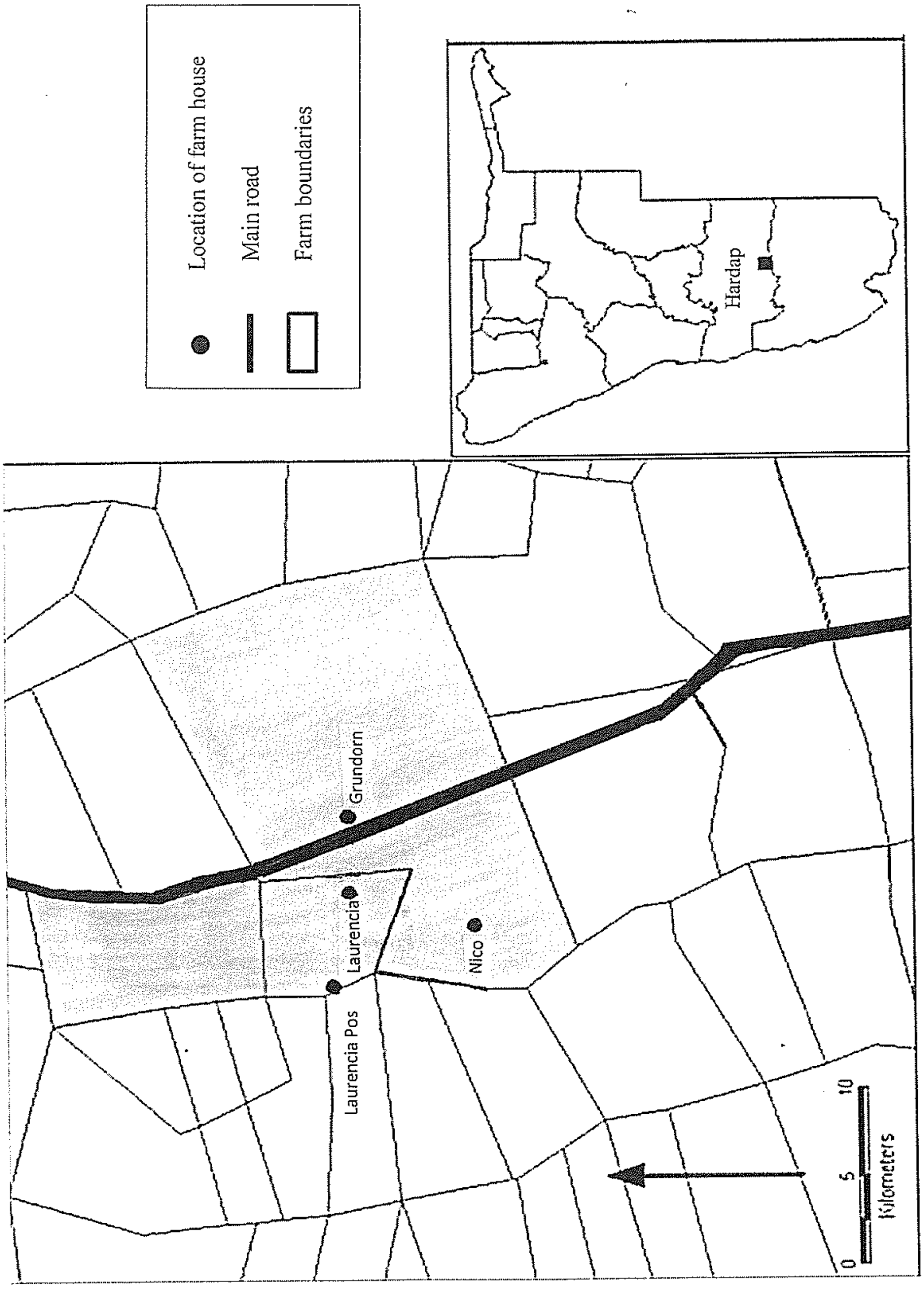

Figure 3.2. Nico, Grundorn, Laurencia and Laurencia Pos are the four Odendaal farms used in the study.

(Source: Simataa 2010)

3.3. Infrastructure of the farms

3.3.1. Grundorn

Gründorn is a farm situated in Hardap Region with 5 people currently residing on it. It is situated 25º 18’ 543” S and 17º 51’ 591” E. It has a diesel pump borehole (Figure 3.3) that is only used by the people and a windmill powered borehole that supplies water for the animals.

Figure 3.3. Diesel water pump at Grundorn.

On the farm, there are 2 broken dams that are not being used anymore. They have pipes connecting water flow from the 5 000L and the 10 000L water tank (Figure 3.4 & 3.5) to the main house. The residents of the farm use grey water to water the garden (Figure 3.6 & 3.7).

Figure 3.4 & 3.5. Water tanks at Grundorn showing rusting and leaking.

Figure 3.6 & 3.7. The garden at Grundorn.

3.3.2. Laurencia

Laurencia is a farm is situated 25º 19’ 198” S and 17º 49’ 495” E. It has a solar powered borehole (Figure 3.8) for anthropogenic use and a windmill powered borehole that supplies water to the animals and to the garden. Currently, there are 15 residents on the farm, and these residents, together with the animals (about 60 sheep, goats and cattle and a few chickens) on the farm only use ±50 000L of water a day.

Figure 3.8. Solar powered borehole at Laurencia.

Figure 3.9. The distance from the animal kraal to the borehole and open dam system.

They have an open dam (Figure 3.9), but it is not used for anthropogenic use. They have a 10 000L water tank and pipes connecting water flow from the water tank (Figure 3.10) to the four houses on the farm. The residents of the farm use grey water to water the garden (Figure 3.11).

Figure 3.10 & 3.11. Water tank and garden at Laurencia.

3.3.3. Laurencia Pos

Laurencia Pos is situated 25º 18’ 746” S and 17º 46’ 291” E in Hardap Region. Currently residing on the farm is only 3 people. The farm has a windmill powered borehole and two 10 000L water tanks (Figure 3.12). The open dam is being used by the residents.

Figure 3.12. Cement dam and water tanks at Laurencia Pos

The people and animals on the farm use ± 10 000L of water a day. The animal pen (Figure 3.13) is situated very near to the borehole itself and a lot of faeces were found in the boreholes vicinity (Figure 3.14).

Figure 3.13 & 3.14. Animal pen and distance between the animal pen and the windmill driven borehole.

3.3.4. Nico

Nico is a farm that is situated 25º 22’ 471” S and 17º 48’ 316” E. There is a windmill powered borehole and a solar powered borehole (Figure 3.16) that supplies water to four permanent residents and animals. They have a lot of animals so they use ± 40 000 L a day. They have two 10 000L water tanks and an open concrete dam with metal sheets around (Figure 3.15), that is being used by the residents.

Figure 3.15. The rusted metal sheets around the dam and one of the water tanks at Nico.

Figure 3.16. Solar powered borehole at Nico.

3.4. Semi-structured interviews

Semi-structured interviews were conducted on the four Odendaal farms in Hardap Region. These farms showed water contamination in previous studies in 2011 and 2016. The farms were Nico, Laurencia, Laurencia Pos and Grundorn. All interviews were conducted with either the owner of the farms or the workers that reside on the farms. The aim of the questionnaire was to get some clarity on the water usage and quality on the farms.

All farms that were part of the study had a borehole, some worked with a diesel pump, some with a solar pump and others were powered by a windmill. All farms had water tanks that they use as storage tanks.

The workers and owners of the farms complained that the water was very brackish at Grundorn, Laurencia, and Laurencia Pos. The owner’s brother at Laurencia even mentioned that you can see the salt on the plants after the water has evaporated. All farms that we sampled had a garden and all farms owners or workers use grey water to water these gardens. The workers on the farm said that the water doesn’t give permanent residents diarrhea, but if an outsider had to drink the water and it was not boiled prior to ingestion, then they would get diarrhea. They also mentioned that children, even though they are permanent residents, still get diarrhea.

Infrastructure on the farms has improved since the 2016 study, as there are less leaking and rusting pipes. All houses also receive water through pipes, except the workers as they still go fetch water at the main house taps in buckets. From the interviews, it was clear that the residents do not use the otji-toilets that were built on the farms, as they say it is built to far from the houses and it doesn’t smell pleasant, but most of them have built their own toilets. The toilets that were built do not have pipes and so do not flush, but Laurencia had a flush toilet in the main house.

Human consumption, cooking, bathing, laundry, and livestock were the primary use of water on these farms, the secondary uses were gardens. In 2016 Gründorn (North) was the only farm sampled without a garden, but as seen from Figures 3.6 & 3.7, they also have a garden now.

3.5. Research Design

A preliminary study to test the water was done on the outskirts of Rehoboth in the Auch district in October 2017. A 500ml water sample was collected at each of the ten farms, namely Soverby Ext 1, Soverby Ext 2, Spitskop, Spitskop Wes 1, Spitskop Wes 2, Vryheid 1 Vryheid 2, Vryheid 3, Vryheid 4 and Vryheid 5. The water was sent to a laboratory to be tested for pH, turbidity, dissolved oxygen, biochemical oxygen demand as BOD, nitrate, nitrite, total phosphate (unfiltered), total solids at 105ºC, total coliforms, faecal coliforms, and *E. coli*. The water showed little to no contamination. The study was then rather conducted in Hardap Region on four Odendaal farms outside Mariental. The non-probability, judgmental sampling method was used as two previous studies by Simataa (2010) and Lewis & Claasen (2016) showed that four farms had substantial contamination of ground water. Only those four farm’s borehole water was sampled to try and improve the water quality, as the main aim of the study was to see which filter could best improve the physico-chemical and biological quality of the sampled borehole water. The study encompassed collecting, filtering and analyzing borehole water on four farms having deteriorated borehole infrastructure as this contributes to water contamination

(Lewis & Claasen 2016). Sampling commenced in June 2019 and every second week, one of the farm's water was collected.

To record the initial water readings, water from the taps connecting to the storage tanks was collected in five sterile 1L borosilicate glass bottles before filtering. The water from the taps was preferred as it is the point of consumption for the residents. If water was sampled directly from the boreholes, further contamination could have occurred before residents actually consumed the water. For filtering, about 270L of water was collected only once at each farm, namely Nico, Grundorn, Laurencia, and Laurencia Pos. Water was collected in 1L, 20L and 50L sterile, polyethylene plastic containers with leak-proof lids and kept at 4ºC with ice packs till filtering took place. Filtering and analysis of the water took place within 48 hours of collecting. Water samples were examined before and after filtering for *E. coli,* total coliforms, nitrate, phosphate, copper, iron, zinc, hardness, turbidity, pH, conductivity and temperature.

3.5.1. Physico-chemical and bacteriological content procedures

NamWater and Analytic Laboratory Services (ALS) use the same water grouping/classification system. Water was graded according to the system applied by NamWater and ALS, to get a clearer understanding of the limit system (Table 3.1).

Table 3.1. Analytic Laboratory Services recommended maximum limits for human consumption**.**

Parameter	**Units**	**Group A**[1]	**Group B**[2]	**Group C**[3]	**Group D**[4]
pH		6-9	5.5-9.5	4-11	0-14
Conductivity	mS/m	150	300	400	>400
Turbidity	NTU	1	5	10	>10
Carbonate hardness	mg/L	375	500	1000	>1000
Nitrate	mg/L	10	20	40	>40
Copper	mg/L	0.5	1	2	>2
Iron	mg/L	0.1	1	2	>2
Total coliforms	cfu/100ml	0	10	100	>100
E. coli	cfu/100ml	0	0	10	>10

3.5.1.1. Physical analysis

On site measurement of turbidity (Figure 3.17), pH, temperature and conductivity was conducted with field probes. All tests were done in triplicates and an average was calculated.

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[1] Water with excellent quality

[2] Water with good quality

[3] Water with low health risk

[4] Water with a high health risk, or water unfit for human consumption

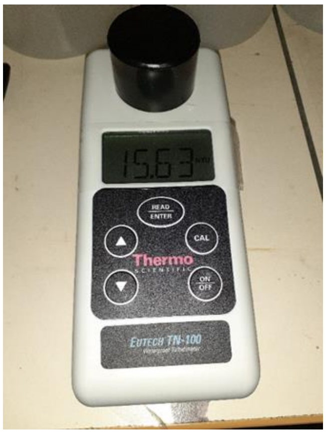


Figure 3.17. The portable turbidity meter used in the study.

After the filtering process the same tests were conducted on the filtered water. The sampled water results was compared to safe drinking water guidelines as recommended by WHO (2018) and grouped according to Analytic Laboratory Services cc Groups.

3.5.1.2. Chemical analysis

The colourmetric system Viscolor ECO was used to determine all chemical tests.

Nitrate: A sample of 5 ml was filled into two measuring tubes using a plastic syringe. The measuring tube was placed on position A in the comparator, the reagent was only added to measuring tube B. Five (5) drops of NO_3^{-1} and 1 level measuring spoonful of NO_3^{-2} were added and mixed for 1 min. After 5 min it was placed on position B in the comparator. The comparator was moved until the colours matched in the inspection hole on top. The measurement reading in the recess on the comparator reed was observed and the mid-values were estimated.

Phosphate: A sample of 5 ml was filled into two measuring tubes using a plastic syringe. The measuring tube was placed on position A in the comparator, only added the reagent to measuring tube B. Six (6) drops of PO_4^{-1} and PO_4^{-2} were added and mixed. After 10 min the measuring tube was placed on position B in the comparator.

The comparator was moved until the colours matched in the inspection hole on top. The measurement reading in the recess on the comparator reed was observed and the mid-values were estimated.

Iron: A sample of 5 ml was filled into two measuring tubes using a plastic syringe. The measuring tube was placed on position A in the comparator, only added the reagent to measuring tube B (Figure 3.18). Five (5) drops of Fe^{-1} were added and mixed; this was left for 3 min and placed on position B in the comparator. The comparator was moved until the colours matched in the inspection hole on top. The measurement reading in the recess on the comparator reed was observed and the mid-values were estimated.

Figure 3.18. Iron test done on Grundorn's groundwater.

Copper: A sample of 5 ml was filled into two measuring tubes using a plastic syringe. The measuring tube was placed on position A in the comparator, the reagent was only added to measuring tube B. Five (5) drops of Cu^{-1} and 5 drops of Cu^{-2} were added and mixed (Figure 3.19). After 10 min the measuring tube was placed on position B in the comparator. The comparator was moved until the colours matched in the inspection hole on top. The measurement reading in the recess on the comparator reed was observed and the mid-values were estimated.

Figure 3.19. Copper test being done.

Zinc: A sample of 1 ml was filled into two measuring tubes using a plastic syringe. The measuring tube was placed on position A in the comparator, the reagent was only added (Figure 3.20) to measuring tube B. Two (2) drops of Zn^{-1}, 2 drops of Zn^{-2} and 5 drops of Zn^{-3} were added and mixed. After 1 min the measuring tube was placed on position B in the comparator. The comparator was moved until the colours matched in the inspection hole on top. The measurement reading in the recess on the comparator reed was observed and the mid-values were estimated.

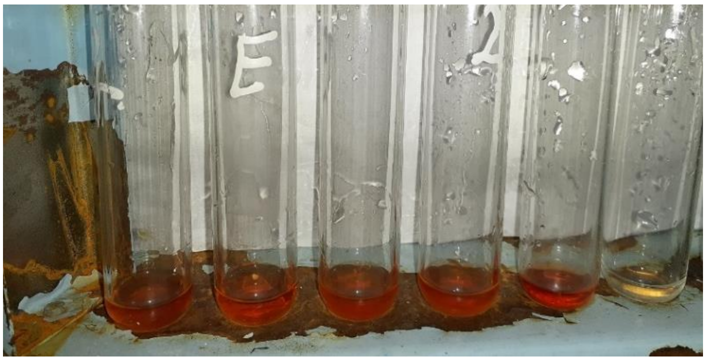


Figure 3.20. Zinc test done on Grundorn's groundwater.

Carbonate hardness: A sample of 5 ml was filled into a measuring tube using a plastic syringe. Two (2) drops of GH^{-1} were added to the measuring tube mixed. The sample turned red (Figure 3.21). If the sample turned green, it means that there were no hardness-producing substances.

Figure 3.21. Carbonate hardness test done on Nico's bucket filtered water.

Held the dropping bottle GH^{-2} absolutely vertical and added GH^{-2} drop by drop, and then shook the specimen at the same time to mix until it turned green. The number of drops was counted. One drop corresponded to one degree of total water hardness (°d), which was then changed to mg/l by multiplying by 10.

Safety precautions: For all chemical tests the dropping bottles were sealed immediately after use and the dropping pipettes were not touched. All measuring glasses and tubes were thoroughly rinsed out with distilled water and sealed.

Disposing of the samples: The used analysis specimens were flushed down the drain with tap water and channeled off to the local sewage treatment works. All the chemicals tested were safe to flush down the drain as prescribed on the visocolor ECO leaflets.

3.5.1.3. Bacteriological analysis

Analysis of *E. coli* and total coliforms was determined using the tube method of serial dilutions as prescribe by WHO (Markey 2009). In the experiment 10 milliliters (10 ml) of borehole water was used as the raw sample, labelled R. Five other test tubes were filled to the 9 ml mark with distilled water named the dilution blanks. The dilution blanks were numbered 1-5. From tube R, 1mL of the sample was pipetted into tube 1 and shaken. Then 1ml of tube 1 was pipetted into tube 2, this continued until tube 5 was filled with 10ml (9ml distilled water and 1mL of sample from tube 4). The dilutions were as follows 10^{o}, 10^{-1}, 10^{-2}, 10^{-3}, 10^{-4} and 10^{-5}.

Three types of agar were used for this study, for *E. coli*, Eosin Methylene Blue Agar was used; 23g of agar was weighed and added to 1L distilled water in a Schott bottle. For total coliforms 17g of Plate Count Agar was weighed and added to 1L distilled water in a glass Schott bottle. Both were autoclaved for 15min at 121ºC. For a combination of *E. coli* and coliforms, Oxoid Brilliance *E. coli*/coliform Selective Agar was used, whereby 28.1g of selective agar was suspended in 1L of distilled water. The medium was gently brought to boiling point to dissolve completely. The liquid agar was plated in petri dishes and left to stand for an hour to solidify. The plates were then marked 10^{o}, 10^{-1}, 10^{-2}, 10^{-3}, 10^{-4} and 10^{-5} according to the dilutions. A pipette was used to transfer 1ml of the dilution mixture from the tube to the agar plates. Using a sterile glass rod, the dilution mixtures were spread evenly on the agar surface; plating took place in a laminar cabinet. The *E. coli* plates were left in the incubator for 24h at 44ºC and the total coliform plates were left in the incubator for 24h at 37ºC. The combined plates were left in the incubator for 24h at 37ºC. The average microbial counts obtained were calculated using the formula:

CFU/mL= (Number of bacterial colonies counted on plate x Dilution Factor) / Volume of culture plate,

following protocol of Dubey and Maheshwari (2002). *E. coli* colonies on the Eosin Methylene Blue Agar were counted as colonies with metallic sheen, or dark blue or dark centers. On the Brilliance *E. coli*/coliform Selective Agar typical *E. coli* colonies were counted as purple and the coliform colonies were counted as pink. The Oxoid Brilliance *E. coli*/coliform Selective Agar was preferred as the agar allowed purple, presumptive-positive *E. coli* colonies to be confirmed directly on the plate by performing the indole reaction. The agar plate was flooded with Kovacs solution (Indole Kovacs) and *E. coli* colonies turned a distinctive cherry red colour, allowing rapid and easy enumeration of confirmed *E. coli* colonies.

For final identification of bacteria Gram staining was performed. A small drop of bacterial sample from the agar plate was transferred from the plate to the slide's surface that had one drop of distilled water on, with a sterilized loop. Then the mixture was air dried and heat fixed. The bacterial smear was then covered with crystal violet for 1 minute, and rinsed with tap water. Then it was covered with Gram's iodine for 1 minute and rinsed with tap water. Acetone was applied drop by drop until the drops came off light purple and rinsed with tap water. It was then counterstained with safranin for 1 minute and rinsed with tap water and then the slide was blotted dry with tissue paper. The slide was then observed under the microscope and the morphology and colour observed to confirm if it is gram negative bacteria.

3.5.2. Preparation of Household Water Filter Devices

3.5.2.1. Preparation of filter media

***Fine sand*:** Fine sand was sieved three times with a 0.5mm sieve. The sand was then washed with tap water and left for 30 min for all impurities to float to the top. It was washed with water at 100ºC to remove some bacteria and any other impurities not washed off with the first wash. The sand was placed in a 2cm layer and baked in an oven at 120ºC for 30min to kill the remaining bacteria. The sand was left in a biltong dryer overnight to get the sand completely dry.

Coarse sand: The sand was sieved three times with a 3mm sieve and a 0.5mm sieve. The sand that passed through the 0.5mm sieve was used as fine sand. The coarse sand was then washed with tap water and left for 30 min for all impurities to float to the top. Then it was washed with water at 100ºC to remove some bacteria and any other impurities not washed off with the first wash. The sand was place in a 1.5cm layer and baked in an oven at 120ºC for 30min to kill the remaining bacteria. The sand was left in a biltong dryer overnight to get the sand completely dry.

Gravel: The gravel was washed 3 times with tap water to remove all impurities on the stones. It was then boiled at 100ºC for 30min to kill some bacteria and remove the remaining impurities. It was then spread out on a sheet and baked at 120ºC for 20min.

***Activated charcoal*:** Activated charcoal was bought and used in the filters.

3.5.2.2. Construction of filters

3.5.2.2.1. Biosand filter

A biosand filter was constructed based on the biosand filter developed by David Manz with some modifications (Buzunis 1995). The filters were constructed with a

25L (40cm: height and 32cm: width) plastic bucket. A hole was drilled 2 cm from the base of the bucket into which a tap was fixed. Each filter had a diffusion plate, made by drilling 2mm holes in the lid of the filter bucket, with a dremel drill (2mm drill bit) as not to disturb the schmutzdecke (biological layer that develops at the top part of the filter media). A 4cm layer of gravel was laid in the bottom of the bucket, on top of that a 4 cm coarse sand layer was laid and the top layer consisted of 17cm fine sand. Six of each filter was constructed (Figure 3.22), to get an average of how the filter performs.

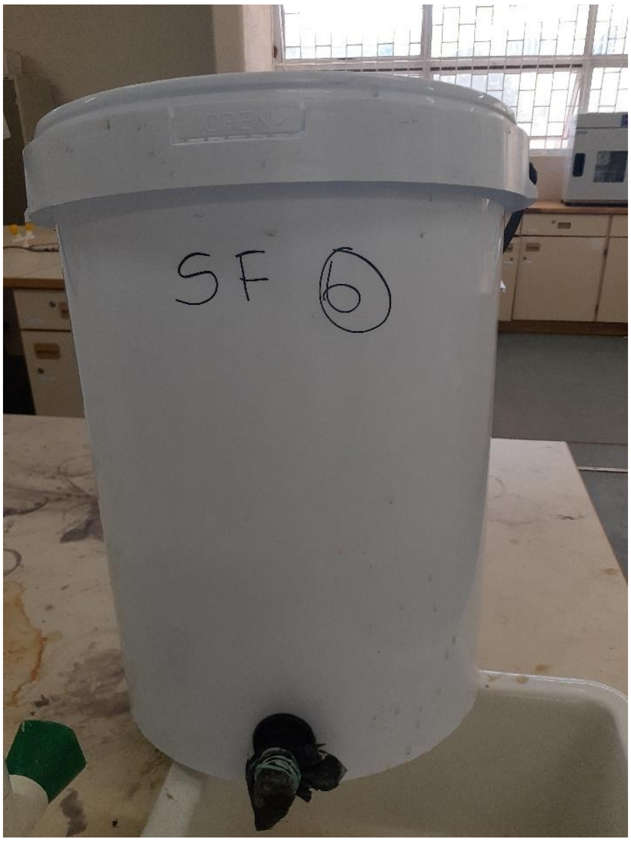


Figure 3.22. Sand filter number 6.

3.5.2.2.2. Bucket filter

A bucket filter was constructed based on the study done by Mwabi *et al*. (2011) with some modifications. The filters were constructed with a 25L (40cm: height and 32cm: width) and a 20L plastic bucket fixed on top of each other. A hole was drilled

2 cm from the base of the bucket into which a tap was fixed. Each filter had a diffusion plate, made by drilling 2mm holes 1 cm apart, in the lid of the filter bucket, with a drill (2mm drill bit) as not to disturb the schmutzdecke. The top bucket’s base was perforated with 3mm holes 1cm apart, to allow water to pass from the top bucket into the bottom bucket. A 5cm layer of gravel was laid in the bottom of the top bucket and the top layer consisted of 20cm fine sand.

Contaminated water was poured into the upper bucket and passed through the filter media and the treated water was collected in the lower bucket through the perforations in the base of the top bucket. Filtration occurred through the thick layer of fine sand and gravel, and the gravel prevented the fine sand from going into the collection bucket through the perforations. Six of each filter was constructed (Figure 3.23 & 3.24), to get an average of how the filter performs.

Figure 3.23. Bucket filter number three and five.

Figure 3.24. All bucket filters during filtering.

3.5.2.2.3. Activated charcoal

The filters were constructed with a 25L plastic bucket (40cm: height and 32cm: width) and a plastic funnel (30cm: height and 32cm: width). A hole was drilled 2 cm from the base of the bucket into which a tap was fixed. Each filter had a diffusion plate, made by drilling 2mm holes in the lid of the filter bucket, with a drill (2mm drill bit) as not to disturb the schmutzdecke. A 7cm layer of activated charcoal was placed in the base of the funnel, on top of that a 5cm gravel layer was laid and the top layer consisted of 13cm fine sand. Six of each filter was constructed, to get an average of how the filter performs.

3.5.2.3. Maturing of the HWFDs

After construction of the filters, tap water was poured onto the diffusion plates of the filters to allow the filters to start maturing, before sample water was collected. The filters were allowed to mature for two and a half (2.5) weeks. In these weeks the biosand and the bucket filters were fed with 10L of water every 24h and the activated charcoal filters were fed with 5L of water as their filtration rate was much slower.

3.5.2.4. Filter maintenance and cleaning

Maintenance of filters was required when the rate of water flow started to slow down, this was done after sampling on the third farm. About 2-3 cm of the fine sand layer was removed. Fine sand was then filled to the total 25cm layer of filtrate in the filter. It took approximately 2 to 3 days to reestablish its normal flow operation (Dalahmeh *et al*. 2012).

3.5.3. Flow Rate Testing

For daily human activity each person requires 25 L/d as prescribed by DWAF (2002). The flow rates of the filters were assessed to determine whether each filter can produce the prescribed volume of water. The flow rates were measured by recording the volume of water collected by the HWFDs over a period of 1h. This was done three times per three hours.

3.5.4. Bacterial Removal Efficiency

The percentage reduction was calculated using this equation:

$$\textbf{\% reduction} = \frac{(A-B)x\ 100}{A}$$

3.5.5. Physico-chemical removal efficiency

The % of nitrate, phosphate, copper, iron, zinc, hardness, turbidity, pH and conductivity reduction by each HWFD was calculated using the following equation:

$$\textbf{\% removal efficiency} = (\text{unfiltered} - \text{filtered}) \div (\text{unfiltered}) \times 100.$$

3.6. Data Analysis

SPSS software was used for analysis. The different boreholes’ physico-chemical and bacteriological content data, the percentage removal efficiency and the flow rates data was tested for normality using Shapiro-Wilk (Varmuza & Filzmoser 2016), if data was normally distributed the means were compared using One-Way ANOVA (Varmuza & Filzmoser 2016), followed by a Tukey-HSD test (Cox 2018), if differences were observed, to see where the differences are. If data was not normally distributed and the means were compared using Kruskal-Wallis (Varmuza & Filzmoser 2016), followed by a Bonferroni correction test (Cox 2018), if differences were observed, to see where the differences are. To see if the filters could remove physico-chemical and bacteriological content from water, Shapiro-Wilk, was used to determine if data was normally distributed. If data was normally distributed, an independent t-test was used, but if data was not normally distributed a Mann-Whitney U test was used (Varmuza & Filzmoser 2016). The relationship between physico-chemical and bacteriological content and the flow rates data was tested for normality using Shapiro-Wilk, if data was normally distributed a Pearson correlation (Cox 2018) was used and if data was not normally distributed a Spearman correlation was carried out (Varmuza & Filzmoser 2016).

3.7. Research Ethics

The research was carried out after the ethical clearance was granted by the University of Namibia Ethics Committee (H-G Campus/506/2019). Water samples were collected with the permission from the farmers. This was done so that the residents on the farms could be informed and explained about what the research objectives were. The informed consent process/permission process involved three key processes:

1. Disclosing information to farmers or farm workers needed to make an informed decision.

2. Explaining the informed consent form and information to the farmers or farm workers.
3. Promoting the voluntariness of the decision about whether or not to participate in the research.

The names of the participants were kept anonymous and participants could have withdrawn from the study at any time without any negative consequences. Water filtered in the laboratory was not used for any other purpose apart from experimental analysis only. The samples were tested against Analytic Laboratory Services and NamWater groupings and WHO (2018) guidelines for drinking water.

CHAPTER 4

4. Results

4.1. Physical water content from different boreholes in Hardap Region.

4.1.1. Temperature

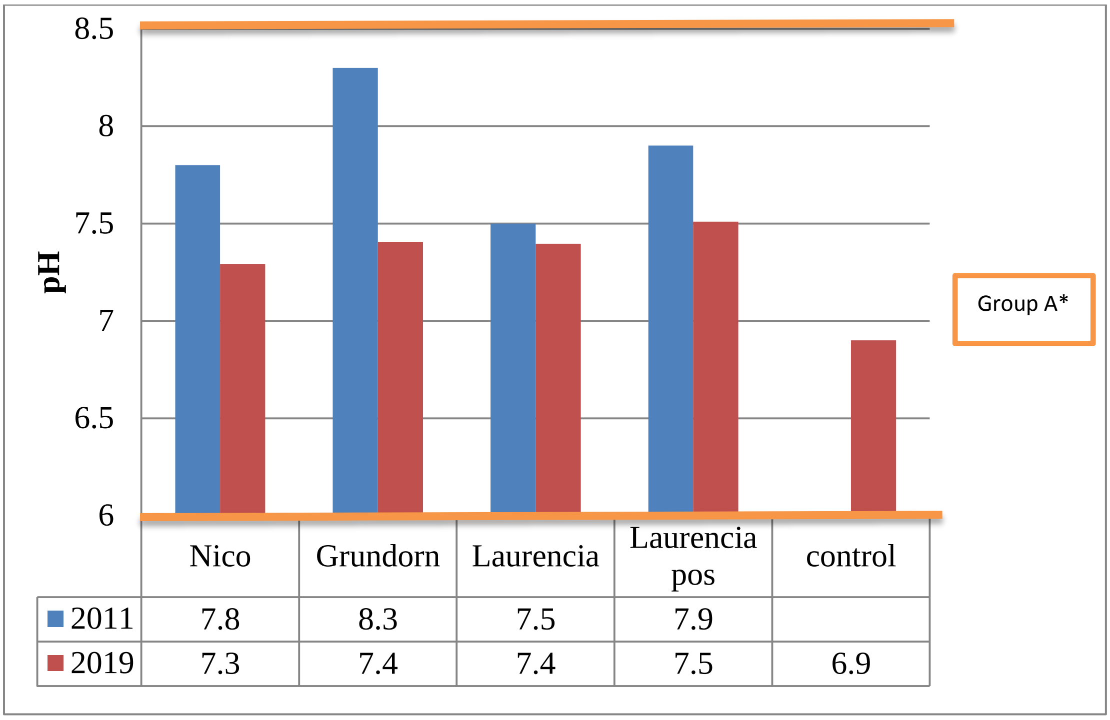
The control's temperature was at room temperature (Table 4.1), while Laurencia Pos had water with a lower temperature. Grundorn's water was also slightly warmer than expected.

Table 4.1. The temperature of water upon collection.

Farm	Temperature (ºC)
Nico	15.87
Grundorn	19.47
Laurencia	16.77
Laurencia pos	14.73
control	22.09

4.1.2. pH

The range displayed by the 2019 graph is classified under the Group A classification (Figure 4.1) of human consumable water, the full pH range of Group A is 6-9.



	Nico	Grundorn	Laurencia	Laurencia pos	control
🟦 2011	7.8	8.3	7.5	7.9	
🟥 2019	7.3	7.4	7.4	7.5	6.9

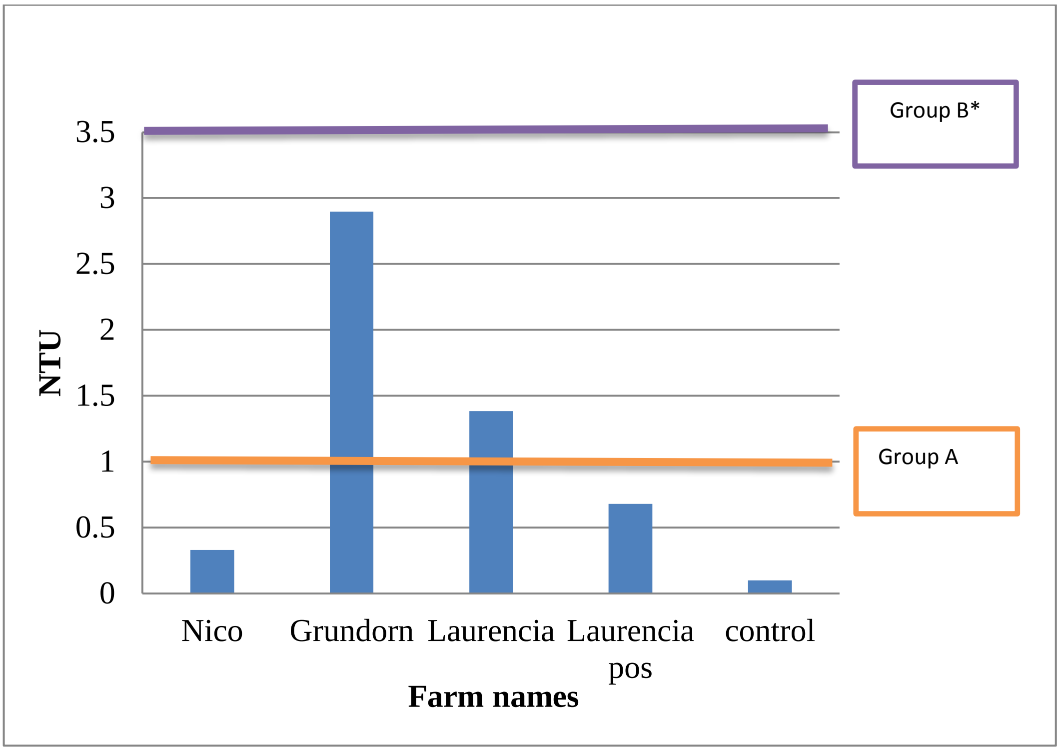
**pH full range for group A is 6-9*

Figure 4.1. The pH levels of the sampled farms for 2011 and 2019.

All sampled farms' borehole water and the control was therefore classified in Group A. Figure 4.1 shows that Laurencia Pos water had the highest pH (7.50 ±0.01) and the control had the lowest pH (6.88 ± 0.04). The four farms and the control's pH levels varied (Kruskal-Wallis, p= 0.013). The difference was between the control and Laurencia Pos (p=0.012). The pH for all farm's borehole water decreased from 2011 to 2019, but they all remained in Group A.

4.1.3. Turbidity

Nico, Laurencia Pos and the control are classified as Group A of water that could be consumed by humans. Grundorn and Laurencia are classified under Group B (Figure 4.2).



**The limit for Group B is 5 NTU.*

Figure 4.2. The turbidity levels of the sampled farms.

Grundorn had the highest turbidity (2.89 NTU ±0.09) and the control had the lowest turbidity (0.10 NTU ± 0.02). The turbidity levels of the farms and the control, varied greatly, p= 0.009 (Kruskal-Wallis). The difference was between the control and Grundorn (p=0.010).

4.1.4. Conductivity

All farms except Nico are classified under Group A classification of human consumable water. Nico's borehole water however fell under Group B (Figure 4.3).

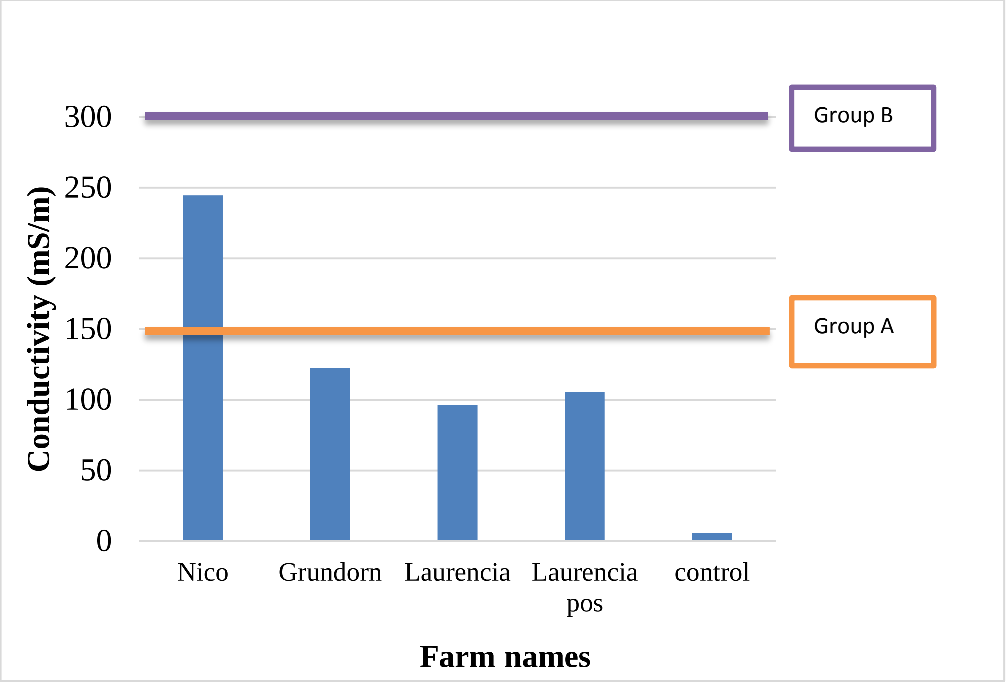


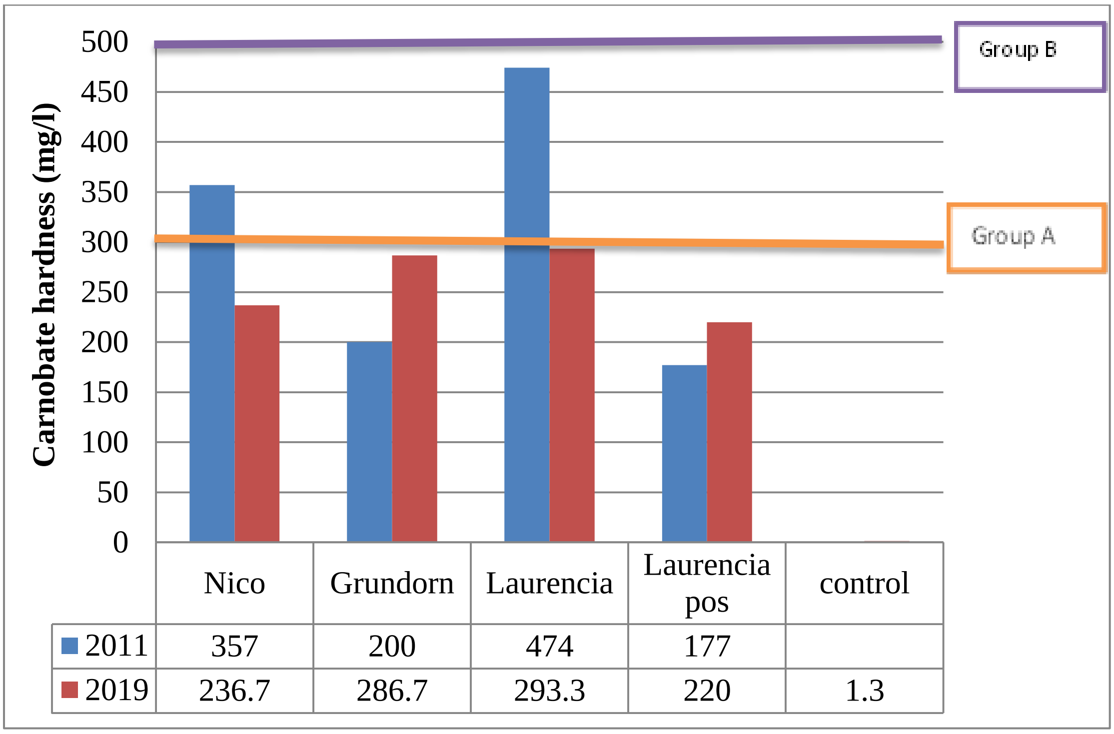
Figure 4.3. The conductivity levels of the sampled farms.

Nico's water had the highest electrical conductivity (244.67 mS/m ± 2.51) and the control (5.67 mS/m ± 0.58) the lowest (Figure 4.3). The four farms and the control's electrical conductivity levels varied greatly (Kruskal-Wallis, p= 0.009). The difference was between the control and Nico (p=0.010).

4.2. Chemical water content from different boreholes in Hardap Region.

4.2.1. Carbonate hardness

The range displayed by the 2019 graph was classified under the Group A classification (Figure 4.4) of human consumable water, the full carbonate hardness range of Group A is 0-300mg/l. All sampled farm's water and the control was therefore classified in Group A.



	Nico	Grundorn	Laurencia	Laurencia pos	control
🟦 2011	357	200	474	177	
🟥 2019	236.7	286.7	293.3	220	1.3

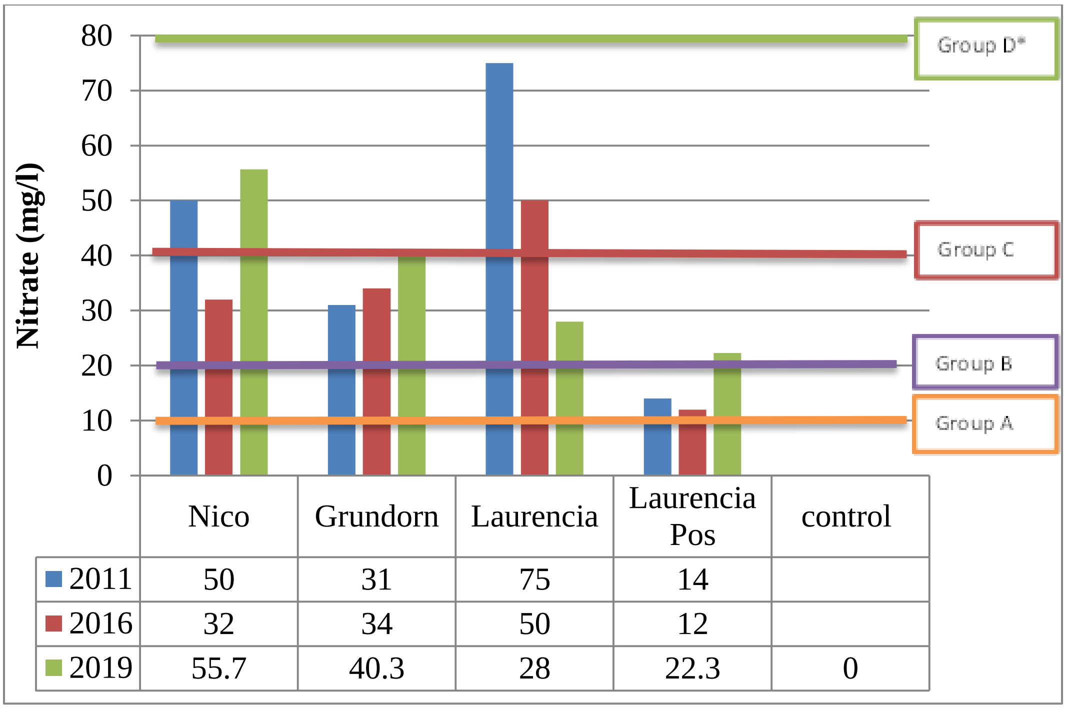
Figure 4.4. The carbonate hardness of the sampled farms for 2011 and 2019.

The graph indicates that Laurencia had the highest level of carbonate hardness (293.3mg/l ± 5.77) and the control had the lowest (1.33mg/l ±5.77). The four farm's carbonate hardness levels varied (Kruskal-Wallis, p= 0.015), as seen from Figure 4.4, confirming a significant difference in the average groundwater carbonate hardness levels from the selected boreholes in Hardap Region. The difference was between the control and Laurencia (p=0.029).

Nico's hardness level in 2011 was Group B and in 2019 it decreased to Group A. Grundorn's hardness level remained within Group B, but it had a slight increase in 2019. Laurencia's hardness level decreased from Group B in 2011 to Group A in 2019. Laurencia Pos's hardness level remained in Group A from 2011-2019.

4.2.2. Nitrate

In 2019, only the control fell under the human consumable water category Group A. No farm’s water was classified under Group A. Laurencia and Laurencia Pos’s water was classified under Group C and Nico and Grundorn under Group D (Figure 4.5). Nico’s nitrate levels in 2011 were unfit for human consumption as it reached the 50mg/l cutoff limit. In 2016 it decreased substantially, however in 2019 it increased (55.70mg/l) way above the limit again. Figure 4.5 displayed that Grundorn’s nitrate levels have increased exponentially over the years and may reach critical levels in the next few years if action is not taken. Laurencia’s nitrate levels have decreased substantially and exponentially over the years; in 2011 it was 75mg/l and in 2019 decreased to 25mg/l falling under the category C of human consumable water. Laurencia Pos’s nitrate levels have also increased from a group B classification in 2011 and 2016 to a group C classification in 2019.



	Nico	Grundorn	Laurencia	Laurencia Pos	control
🟦 2011	50	31	75	14	
🟥 2016	32	34	50	12	
🟩 2019	55.7	40.3	28	22.3	0

**Group D does not have an upper limit.*

Figure 4.5. The nitrate levels of the sampled farms for 2011, 2016 and 2019.

Nico's groundwater had the highest concentration (55.67 mg/l ± 4.73) exceeding the WHO (2018) guideline of 50mg/l, making it unfit for human consumption. The control was free from nitrate (Figure 4.5) and Laurencia Pos's groundwater had the lowest concentration (22.33 mg/l ± 0.58) of nitrate. In 2019 the four farms showed a significant difference in their nitrate levels (One-Way ANOVA, p= 0.00). Tukey HSD post hoc test indicated that the differences were between all farms except Laurencia and Laurencia Pos (p=0.087).

4.2.3. Phosphate

Grundorn's groundwater had the highest concentration (0.67 mg/l ± 0.15). The control was free from phosphate and Laurencia Pos' groundwater had the lowest concentration (0.5 mg/l) of phosphate (Figure 4.6).

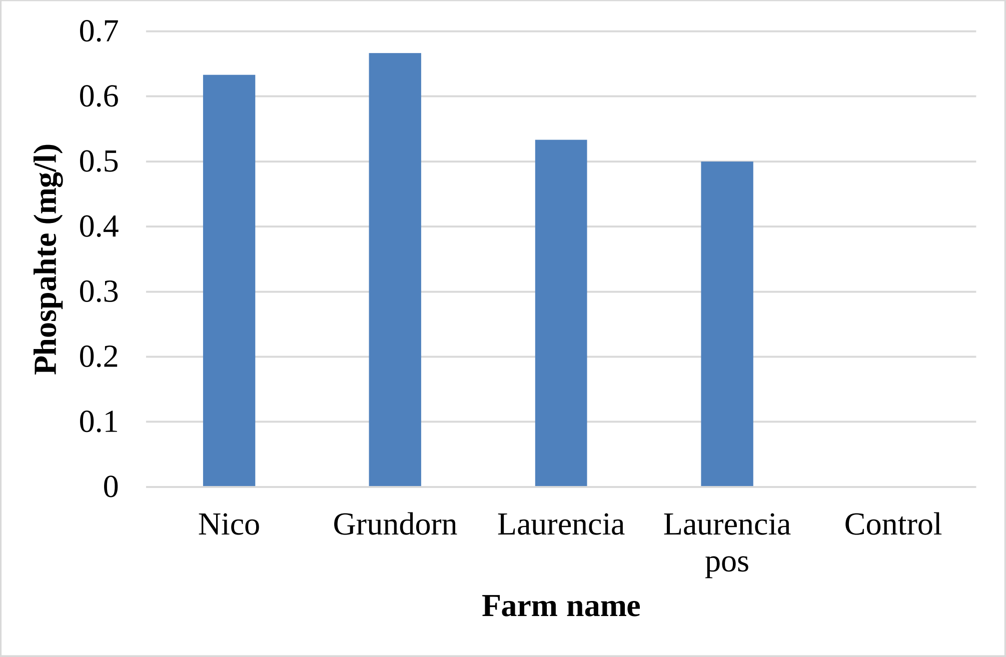
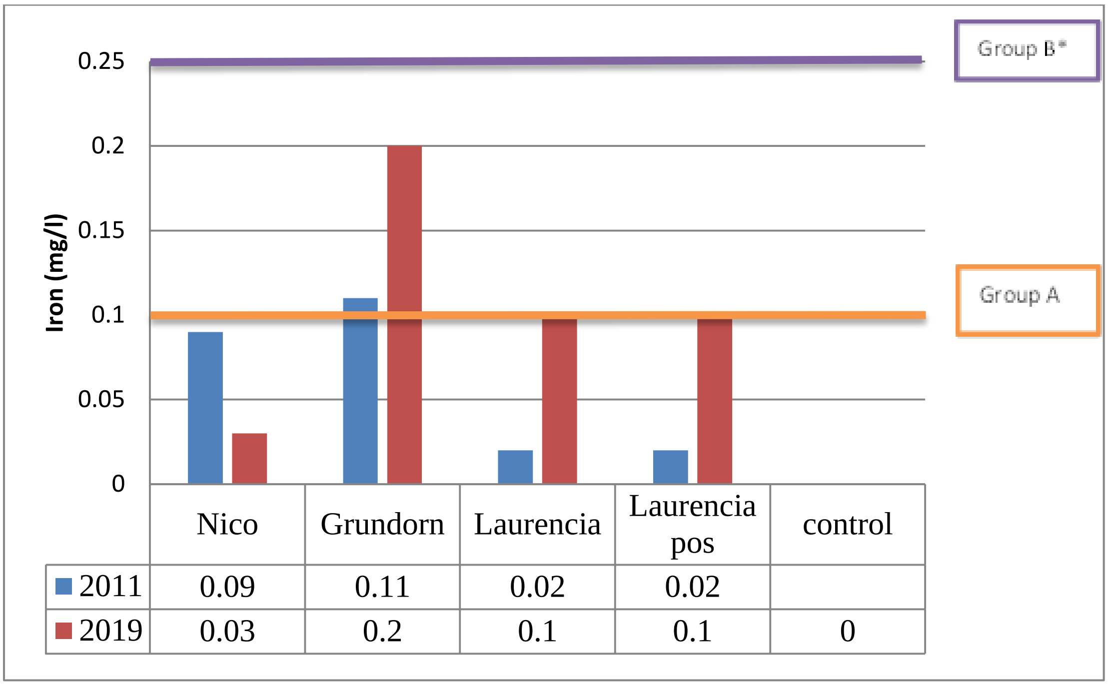


Figure 4.6. The phosphate levels of the sampled farms for 2019.

The four farm's phosphate levels varied slightly (Kruskal-Wallis, p=0.042), as seen from Figure 4.6. The difference was between the control and Grundorn (p=0.028).

4.2.4. Iron

All farms except Grundorn were classified under Group A classification of human consumable water. Grundorn, however, was in Group B.



	Nico	Grundorn	Laurencia	Laurencia pos	control
🟦 2011	0.09	0.11	0.02	0.02	
🟥 2019	0.03	0.2	0.1	0.1	0

**The limit for Group B is 1mg/l.*

Figure 4.7. The iron levels of the sampled farms.

The four farm's iron levels did not vary substantially as seen from Figure 4.7. When statistically tested, there was no significant difference (Kruskal-Wallis) in the average groundwater iron levels from the selected boreholes in Hardap Region.

Nico's iron levels remain in Group A even though it decreased slightly from 2011 to 2019. Grundorn's iron levels for both years were in Group B, although it increased from 2011 to 2019. Laurencia and Laurencia Pos's iron levels remained in Group A for both years, even though both farms iron levels increased from 2011 to 2019.

4.2.5. Zinc

Nico’s groundwater had the highest concentration (0.60 mg/l ± 0.10). The control was free from zinc and Laurencia Pos’s groundwater had the lowest concentration (0 mg/l) of zinc (Figure 4.8).

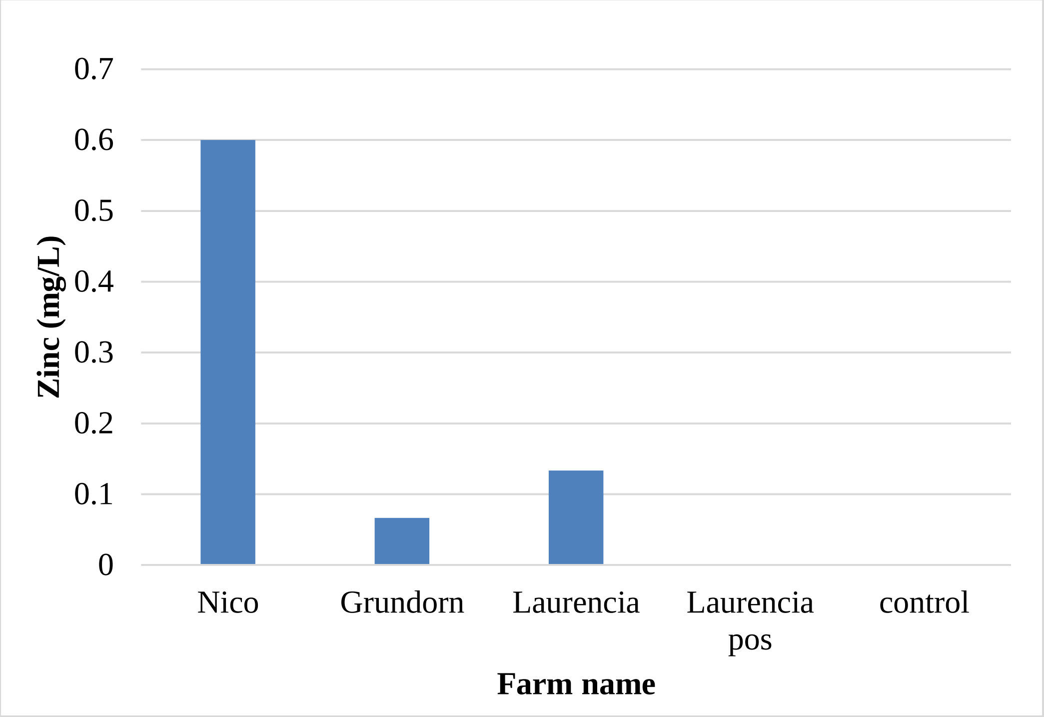
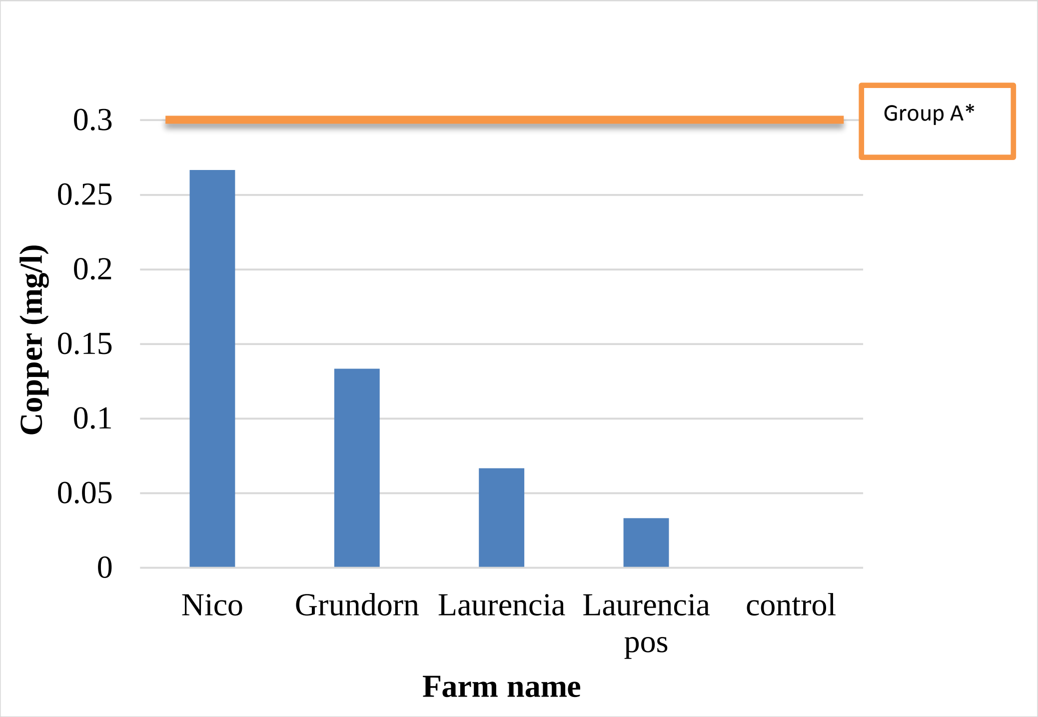


Figure 4.8. The zinc levels of the sampled farms.

The four farm’s zinc levels varied (Kruskal-Wallis, p= 0.014) as seen from Figure 4.8, showing that there is a significant difference in the average groundwater zinc levels from the selected boreholes in Hardap Region. The variation was between the control and Nico (p=0.035) and Nico and Laurencia Pos (p=0.035).

4.2.6. Copper

All farms were classified under Group A classification of human consumable water (Figure 4.9).



**0.5 mg/l is group A's limit, group B's limit is 1mg/l.*

Figure 4.9. The copper levels of the sampled farms.

Nico's groundwater had the highest concentration (0.27 mg/l ± 0.06). The control was free from copper and Laurencia Pos's groundwater had the lowest concentration (0.03 mg/l ± 0.06) of copper (Figure 4.9). The four farm's copper levels varied (Kruskal-Wallis, p= 0.025), proving that there is a significant difference in the average groundwater copper levels from the selected boreholes in Hardap Region. The difference was between the control and Nico (p=0.028).

4.3. Microbiological water content from different boreholes in Hardap Region.

4.3.1. Gram staining

After plate counting, fifty purple *E .coli* colonies were randomly selected and gram staining was performed. After gram staining the bacteria were viewed under a microscope for final identification. The slides gave a selfsame result of pink colour, rod shaped and chain like arrangements (Figure 4.10), confirming the bacteria found was *E. coli* and gram negative bacteria.

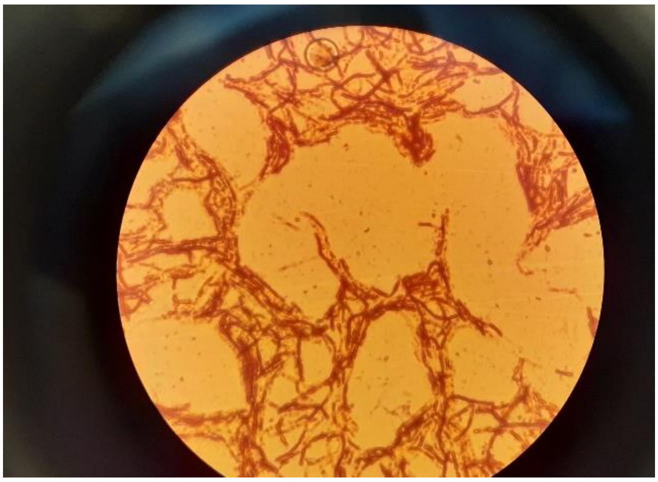


Figure 4.10. The view through the microscope at X500 magnification.

4.3.2. Total coliforms and *E. coli*

Bacterial results were read off from the first fold (dilution 10^{-1}), as the raw data gave values >300 and the 5th fold (dilution 10^{-5}), providing mostly 0 values especially for *E. coli.*

The *E. coli* and total coliform counts varied for all four farms and the control, as seen from Table 4.2, Nico had the highest (1574 cfu/ml ± 8.00) *E. coli* counts and Laurencia Pos had the lowest (122.67 ± 4.62) *E. coli* counts. Laurencia Pos had the highest (1982 ± 11.06) total coliform count and Laurencia the lowest total coliform count. The data for *E. coli* and total coliforms showed that p= 0.000 and p= 0.004 (Kruskal-Wallis), respectively, indicating that there is a significant difference in the average *E. coli* and total coliform counts from the selected boreholes in Hardap Region. The difference for *E. coli* was between the control and Laurencia (p= 0.031) and the control and Nico (p= 0.000) and the difference for total coliforms was between the control and Laurencia Pos (p=0.004). All farms were classified under Group D classification of human consumable water for *E. coli* and total coliform counts and the control falls under Group A.

Comparisons for *E. coli* and coliforms for 2011, 2016 and 2019 was not done for microbiological data as the three studies used different techniques and different fold readings, so comparisons would not be practical.

Table 4.2. Bacterial summary of groundwater samples.

Farm name	***E.coli* cfu/ml (Ave ± SD)**	**Total coliforms cfu/ml (Ave ± SD)**
Nico	1574 ± 8.00	1776 ± 6.58
Grundorn	352 ± 1.89	1772.55 ± 9.92
Laurencia	682.5 ± 3.89	1656 ± 9.69
Laurencia Pos	122.67 ± 4.62	1982 ± 11.06
Control	0	0

4.4. Removal efficiency

When observing Table 4.3, the bucket filter did not remove any physical parameters and nitrate of the borehole water. The charcoal filter added to the turbidity level, but had a percentage removal for all other physico-chemical and bacteriological content.

The sand filter added to the conductivity and turbidity levels, but had a percentage removal for all other physico-chemical and bacteriological content. But when statistically tested it showed that only carbonate hardness (Independent samples T test, p=0.015), total coliforms (Mann-Whitney U, p=0.002) and *E. coli* (Mann-Whitney U, p=0.001) was removed by the filters.

Table 4.3. Removal efficiencies of different filters (before statistical tests).

	% removal efficiency		
Parameter	**Bucket filter**	**Charcoal filter**	**Sand filter**
pH	-2.8	0.1	0.3
Conductivity	-42.1	12.4	-48.5
Turbidity	-177.5	-39.7	-132.4
Phosphate	9.5	3.0	8.3
Nitrate	-7.8	51.8	47.3
Copper	83.7	77.8	79.3
Iron	40.5	52.8	81
Zinc	20.4	67.6	77.8
Carbonate hardness	18.6	67.7	27.7
Total coliforms	84.2	74.9	91.9
E.coli	96.2	98.1	99.6

The three filter’s percentage carbonate hardness removal levels varied (p= 0.00). The charcoal filter had the highest percentage removal efficiency of carbonate hardness (56%) as seen in Figure 4.11.

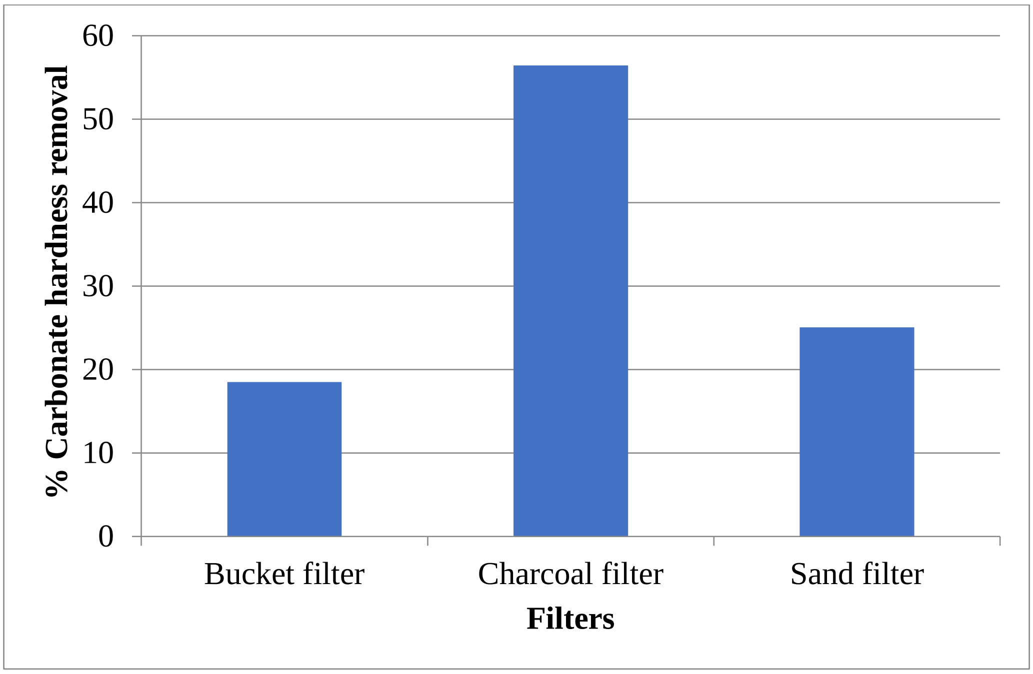


Figure 4.11. The percentage carbonate hardness removal efficiency between the three filters.

The differences was between the bucket filter and the charcoal filter (p=0.000) and the sand filter and the charcoal filter (p=0.001).

There is a significant difference in the percentage removal efficiency of total coliforms from the three filters (p= 0.000). The charcoal filter had the highest percentage removal efficiency of total coliforms (91.9 %) and the charcoal filter had the lowest percentage removal efficiency of total coliforms (74.9 %) as seen from Figure 4.12.

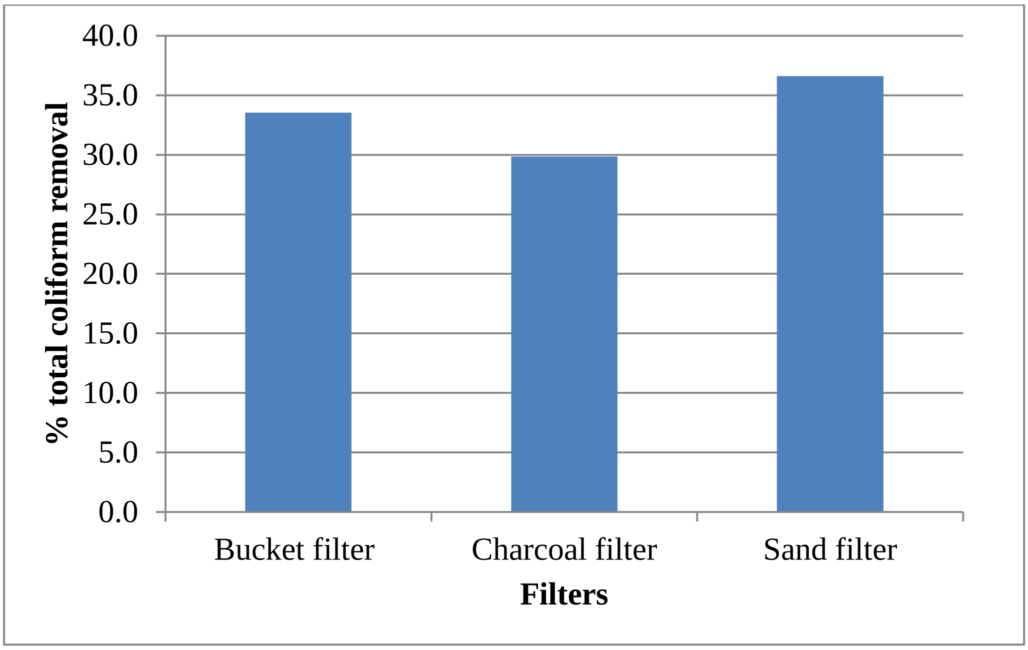


Figure 4.12. The % removal of total coliforms between the three filters.

The differences was between the charcoal filter and the sand filter (p=0.001).

All remaining physico-chemical and bacteriological removal efficiency data were not normally distributed and none of the three filters had any differences in their removal efficiencies (phosphate p= 0.978, iron p= 0.072, zinc p= 0.312, copper p= 0.948, and *E. coli* p= 0.059, so p>0.05). Nitrate, however showed that that p= 0.00, therefore it confirmed that there was a significant difference in the percentage removal efficiency of nitrate from the three filters. The differences was between the bucket filter and the sand filter (p=0.001) and the bucket filter and the charcoal filter (p=0.001).This is because the bucket had an increase in its nitrate concentration rather than a decrease.

4.5. Flow rates

From Figure 4.13 it is clear that the bucket filter had the highest average flow rates (3 L/h ± 0.13) and the charcoal filter had the lowest average flow rates (0.72 L/h ± 0.07).

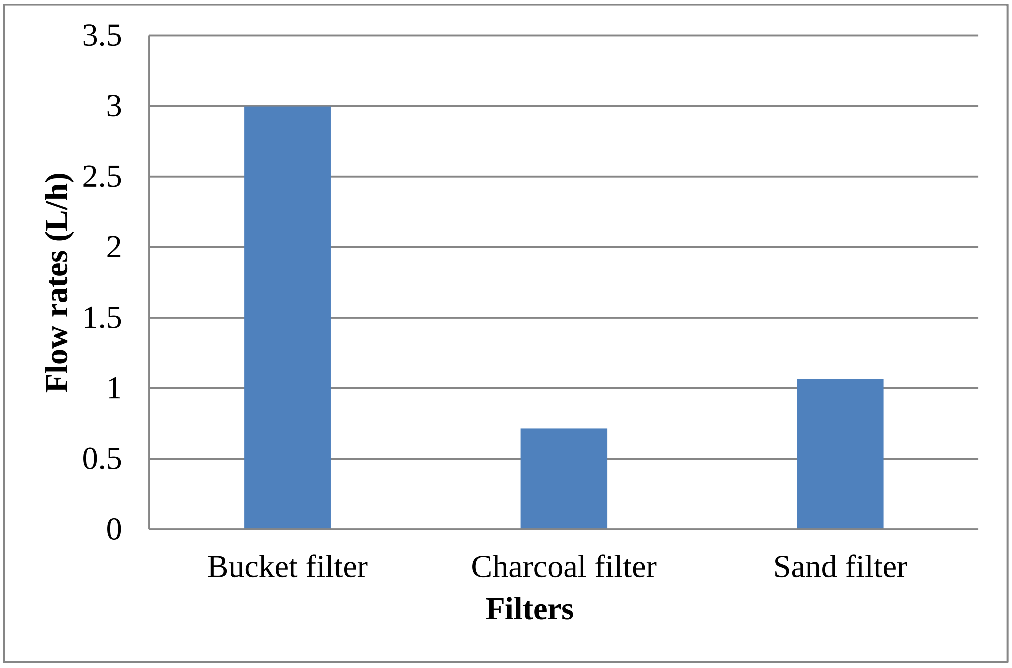


Figure 4.13. The average flow rates of the three filters.

The three filter’s flow rates varied (Kruskal-Wallis, p= 0.00), as seen from Figure 4.13, meaning there is a significant difference in the flow rates between the three filters. The differences was between the bucket filter and the charcoal filter (p=0.000) and the sand filter and the bucket filter (p=0.001).

From Figure 4.14 it is clear that the charcoal filter did not meet the minimum water requirement for daily human activity.

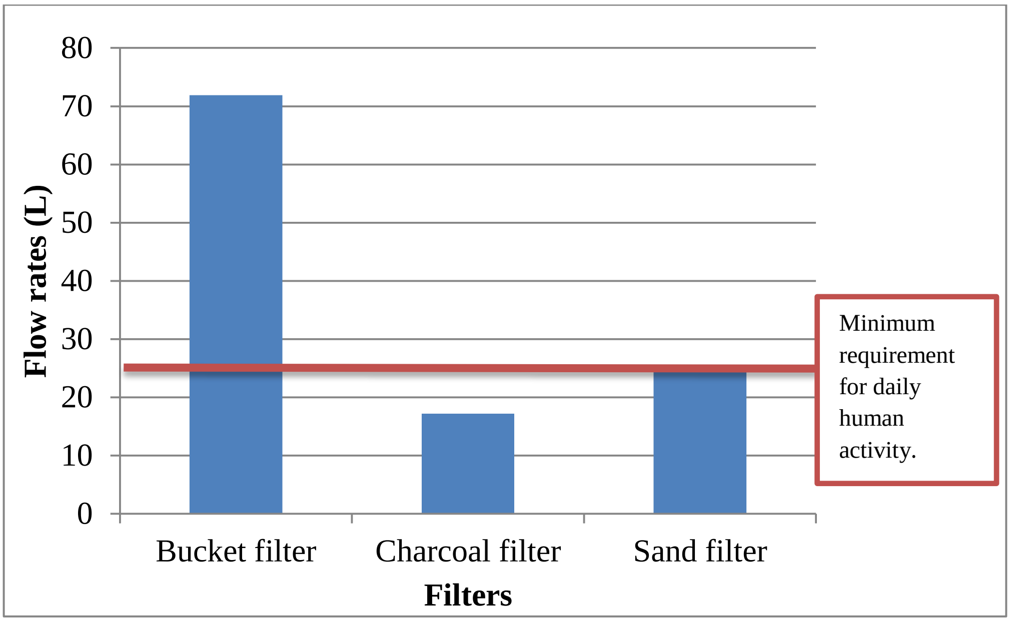


Figure 4.14. Minimum requirement for daily human activity of the three filters per day/24h.

The sand filter met the minimum requirements for a person and the bucket filter far exceeded the minimum water requirement for daily human activity.

It is observed from Figure 4.15, that the flow rates decrease with increased use of the filters.

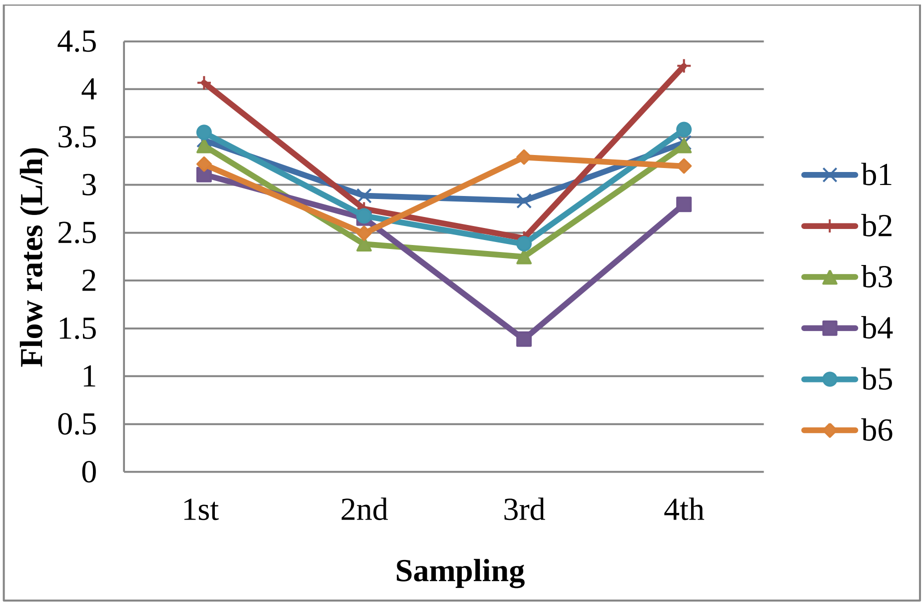


Figure 4.15. The flow rates of the bucket filter as sampling commenced.

From the 1st sampled farm to the 3rd sampled farm the average flow rates decreased and most of them increased again on the 4th sampling. Filter b6 did not follow the same pattern between the 2nd and 3rd sampling (Figure 4.15)

It is observed from Figure 4.16, that most flow rates decreased with increased use of the filters.

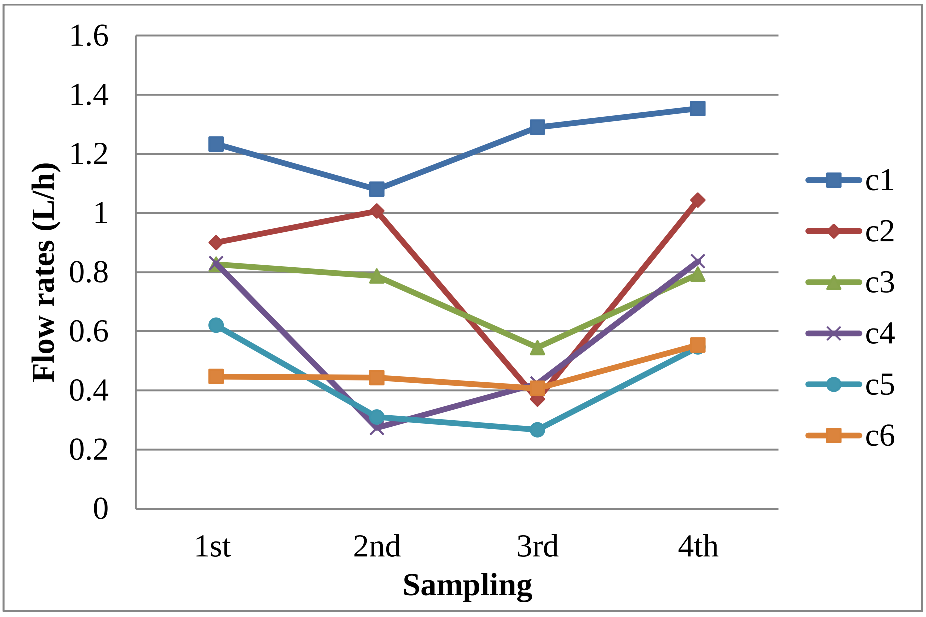


Figure 4.16. The flow rates of the charcoal filter as sampling commenced.

From the 1st sampled farm to the 3rd sampled farm the average flow rates decreased and most of them increase again on the 4th sampling. Filter c2 did not follow the same pattern between the 1st and 2nd sampling. Filter c1 and c4 also diverted between the 2nd and 3rd sampling (Figure 4.16).

From Figure 4.17, it is clear that most of the flow rates increased from the 1st sampled farm to the 2rd sampled and then decreased from the 2nd sampled farm to the 4th sampling.

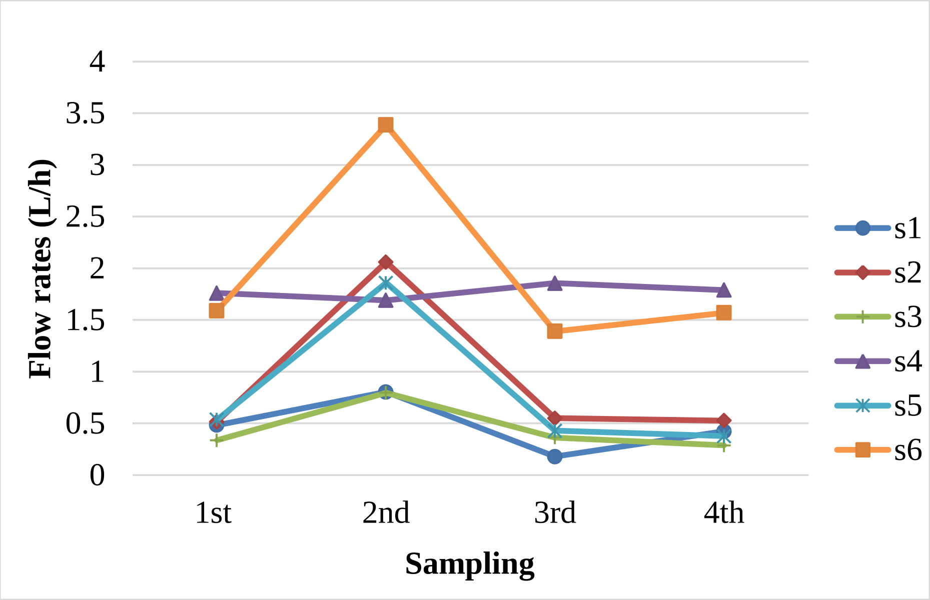


Figure 4.17. The flow rates of the sand filter as sampling commenced.

Filter s4 did not follow the same pattern between the 1st and 2nd sampling. Filter s1 and s6 also diverted between the 3rd and 4th sampling (Figure 4.17).

4.6. Relationship between flow rates and physico-chemical and bacteriological removal content

Table 4.4 shows that there is a weak relationship between most of the parameter's removal efficiency and the flow rates of the filters (Spearman correlation). The weak relationships are more negative than positive. The bucket filter's nitrate, copper, carbonate hardness and conductivity content removal were moderately related to its flow rates. Only the turbidity content removal and the flow rates of the charcoal filter were moderately related. All the other removal parameters and the flow rates had a weak relationship. The sand filter's carbonate hardness, total coliforms and *E. coli* content removal were moderately related to its flow rates.

Table 4.4. The relationship between the flow rates and the removal efficiency.

Relationship table				
Parameters		**Filter**	**r value**	**Relationship**
Flow rates	pH	Bucket	-0.038	Weak negative correlation
		Charcoal	0.326	Weak positive correlation
		Sand	0.363	Weak positive correlation
Flow rates	Conductivity	Bucket	0.593	Moderate positive correlation
		Charcoal	-0.141	Weak negative correlation
		Sand	0.170	Weak positive correlation
Flow rates	Turbidity	Bucket	-0.169	Weak negative correlation
		Charcoal	-0.414	Moderate negative correlation
		Sand	0.276	Weak positive correlation
Flow rates	Carbonate hardness	Bucket	0.517	Moderate positive correlation
		Charcoal	-0.360	Weak negative correlation
		Sand	-0.401	Moderate negative correlation
Flow rates	Nitrate	Bucket	0.464	Moderate positive correlation
		Charcoal	0.027	Weak positive correlation
		Sand	0.021	Weak positive correlation
Flow rates	Phosphate	Bucket	-0.272	Weak negative correlation
		Charcoal	-0.322	Weak negative correlation
		Sand	0.273	Weak positive correlation
Flow rates	Copper	Bucket	-0.476	Moderate negative correlation
		Charcoal	-0.287	Weak negative correlation
		Sand	0.269	Weak positive correlation
Flow rates	Iron	Bucket	-0.116	Weak negative correlation
		Charcoal	0.127	Weak positive correlation
		Sand	0.313	Weak positive correlation
Flow rates	Zinc	Bucket	-0.100	Weak negative correlation
		Charcoal	-0.229	Weak negative correlation
		Sand	0.210	Weak positive correlation

Flow rates	Total coliforms	Bucket	0.348	Weak positive correlation
		Charcoal	0.036	Weak positive correlation
		Sand	0.438	Moderate positive correlation
Flow rates	*E.coli*	Bucket	-0.082	Weak negative correlation
		Charcoal	-0.019	Weak negative correlation
		Sand	0.517	Moderate positive correlation

CHAPTER 5

5. Discussion

5.1. Physico-chemical and bacteriological content of borehole water in Hardap Region

Physically and chemically speaking 50% of the farms e.g. Laurencia and Laurencia Pos had good quality water (Grade/ Group B), 25% of boreholes sampled (Grundorn) had water of low risk (Group C) and 25% of boreholes (Nico) sampled had water that was unfit for human consumption. Biologically speaking 100% of the boreholes sampled had water that was unfit for human consumption.

Warmer water, combined with organic matter, moisture and oxygen availability, will increase the probability for micro-organisms to breed, causing water to taste different and it can affect the water's odour and colour. Temperature has an impact on the acceptability of inorganic constituents and chemical contaminants that may affect the taste of the water (WHO 2018). The water's pH usually has no direct impact on the consumer and is usually in the range of 6.5-8.5 (WHO 2018). Acidic water (pH less than 7) usually corrodes water pipes; this is why not a lot of rusting and deteriorated pipes were observed, as all farms had either neutral or slightly acidic water (Figure 4.1). The major cause of iron corrosion is pH. Between the ranges of 6.8–7.3, which most farms' pH levels was very little corrosion of iron takes place (Ponsadailakshmi *et al.* 2018). This could be the reason why most farms infrastructure was not too badly rusted. The iron concentration on almost all farms increased from 2011 to 2019, because of infrastructural corrosion (WHO, 2018). For Nico, however, the iron concentration decreased because new pipes had been installed. Less than 0.3mg/l of iron in water, as detected from all farm's borehole water, will not let the water change colour. Distilled water, has a pH of 7, but as the temperature of the water increases its pH level decreases (Rajappa *et al.* 2010). This showed from the control used, that the pH reading for the control is less than the farms pH readings, while its temperature reading is the highest. All farms pH levels basically stayed the same from 2011 to 2019, with a slight decrease. The reason that the pH of sampled farms decreased between 2011 and 2019, could have been that sampling took place at different times of the day, so in 2011 it could have just been warmer. Usually as temperature increases, water molecules break apart and increase the hydrogen ions, thereby decreasing the pH of the water (Palamuleni & Akoth 2015). Results from studies done in South Africa (Palamuleni & Akoth 2015 and Taonameso *et al.* 2019) showed that the normal pH range of borehole water is between 6-8, which this studies result confirmed.

Turbidity is usually caused by several reasons. Turbid water is usually a muddy red-brown colour and this discourages the consumers from drinking the water (Ponsadailakshmi *et al.* 2018). Although most particles that contribute to turbidity have no health significance (WHO 2018), consumers associate high turbidity with unsafe drinking water. When the water reaches a turbidity level of 5 NTU, the water is no longer safe to consume as prescribed by WHO (2018). The test results from Figure 4.2 displayed clearly that all sampled farm's borehole water had a turbidity level of less than 5 NTU, stating that the water in terms of turbidity is safe to drink and satisfactory without filtration. Studies done in Mahikeng (Palamuleni & Akoth 2015) and Siloam Village, South Africa (Odiyo 2018) showed that the turbidity levels of boreholes fall in about the same range of 0.1-5, with some exceptions.

The electrical conductivity of drinking water is the ability of this water to conduct an electric current (Ponsadailakshmi *et al.* 2018). Usually the purer the drinking water, the lower the conductivity. Groundwater, with high temperatures can dissolve a lot more minerals from the surrounding rock and will therefore have a higher electrical conductivity. Water with a conductivity between 0mS/m to 80mS/m is considered good drinking water for humans (Mohsin *et al.* 2013). Water between 80mS/m to 250mS/m can be consumed by humans, although it would be preferred at a lower range. All of the farms' borehole water falls into this 80mS/m to 250mS/m range and this is because there is a moderate concentration of mineral salts that have dissolved in the water (Mohsin *et al.* 2013). These mineral salts like sodium, calcium and magnesium could have leached from the rocks and ground in the borehole or water table (Simpson & Meixner 2012). Previous studies in Vhembe District, Limpopo Province of South Africa, with similar climatic conditions, also indicated that the borehole water conductivity levels ranged between 85-500mS/m (Taonameso *et al.* 2019).

Calcium and magnesium caused hardness is usually specified by soap not wanting to lather. The change in visitors' drinking water's magnesium content and the farms' high levels of magnesium in the water could have also been the reasons for visitors on these farms to get diarrhea (Nkamare *et al.* 2012). Hard water with hardness above 200 mg/l usually causes scale deposition in the pipework and tanks on the farms, causing farm owners and workers to use more soap when cleaning. This was observed on all four farms. The carbonate hardness levels for Nico and Laurencia decreased from 2011 to 2019, for Grundorn and Laurencia Pos the carbonate hardness level increased over the years because of calcium and magnesium that leach from the rocks in the water table into the borehole's water (Anku *et al.* 2009). When water with calcium carbonate in is heated it starts to form calcium carbonate scales (Ponsadailakshmi *et al.* 2018). One of the farmers reported that white scales were seen on plants later in the day if they water the gardens in the mornings. None of the sampled farms had soft water. Soft water is water with a hardness of less than 100 mg/l and it cause water pipes to corrode more easily.

For Nico, in 2011 the nitrate level just reached the WHO (2018) guideline limit, but in 2016 it decreased extremely. In 2019 the nitrate levels increased again above the WHO (2018) guideline, revealing that the water was unfit for human consumption as it had a very high level of nitrate, 55.6mg/l. Nico's residents had many livestock e.g. cattle, goats, sheep and chickens, that defecate anywhere. Graham & Polizzotto (2013) emphasized that faeces are composed of nitrates and phosphates and these chemicals lead to pollution if they enter a water system. These livestock's faecal matter could be the cause of the high nitrate levels at Nico (Lewis & Claasen 2018). Studies in areas of South Africa and Botswana with similar climatic conditions showed that the normality range of nitrate in boreholes was much less than Nico's nitrate levels (Palamuleni & Akoth 2015 and Batisani 2012). Grundorn's animal pen is situated more than 100m from the borehole, so less feacal pollution took place (Rahman 2008). The fact that the people on the farms don't use the otji-toilets anymore as they said that it is built far from the houses and it doesn't smell pleasant, could also be a reason for the high nitrate levels. The nitrate levels increased exponentially over the years (2011, 2016 and 2019), this could be due to fertilizers, as they have a garden or the buildup of soil organic matter (Ponsadailakshmi *et al.* 2018). Laurencia's nitrate water classification moved from a Group D in 2011 to a Group C in 2019, this might be due to the fact that Namibia had a period of drought in these years and so the lack of rainfall, and hence the lack of dilution may have caused concentration of solutes in water (McGill *et al.* 2019). This decrease in nitrate could also be because the owners put up a fence so that the livestock could not roam in the vicinity of the borehole. Laurencia Pos nitrate water classification moved from a Group A in 2011 and 2016 to a Group B in 2019. The reason for this was that the people living there still used the otji-toilets, but they used the human feaces as manure for the plants. This manure contains a lot of bacteria and depending on its strain and its environmental conditions, the survival of these bacteria varies greatly (Lewis & Claasen 2018). These bacteria can live in manure for over a year, and when it rains water and this manure infiltrates into the groundwater, contaminating it (Ekklesia *et al.* 2015).

Phosphorus is usually found in water as phosphates (WHO 2018). These phosphates in the sampled water could have originated from human and animal waste, as the farm workers are still using the bush or bucket method and livestock is permitted to roam in the vicinity of the borehole. Other sources usually include leaching from rocks, industrial wastes, soil erosion and fertilizers (Ponsadailakshmi *et al.* 2018). Phosphates in water cause algae to grow; this was observed on all the farms in the open dam systems (Fadiran, Dlamini, & Mavuso 2008). Phosphates are not an immense problem in drinking water, as there is no controlled limit for it, but WHO (2018), has provided a maximum 'safe' level of around 5mg per liter, which none of the farms exceeded. WHO (2018) also has a RDA (Recommended Daily Allowance) of phosphate intake for humans that should not exceed 800mg.

A high level of zinc in drinking water causes an undesirable taste to the water (Ponsadailakshmi *et al.* 2018). Although drinking water rarely contains zinc at concentrations above 0.1 mg/l, older galvanized plumbing materials that are made of zinc can affect the zinc concentrations (Rajappa *et al.* 2010). The test results from Figure 4.8, displayed that Laurencia had a concentration of slightly above 0.1mg/l, but Nico had a higher concentration of 0.6mg/l, which could be because of erosion of minerals from rocks and soil, from the borehole, or high concentrations of other metals such as lead and cadmium (Batayneh, 2012). If drinking water contains zinc at levels higher than 3mg/L it starts to develop a greasy film when boiled and it has an undesirable sharp taste (Batayneh 2012).

Copper, usually enters a water source when the corroded materials start to dissolve in the water. How easily the copper can mix with the water depends on the pH of the water, the higher the pH the more difficult it is for copper to dissolve in the water (Rajappa *et al.* 2010). Both the pH levels and the copper levels of the groundwater tested were within the safe human consumption level, denoting that it is good quality water.

Coliform bacteria are the most commonly used indicator organisms for water quality testing, and they show if water is polluted through faecal contamination, therefore testing for them was crucial in this study as rural communities struggled with healthy sanitation practices (Simataa 2010). Some rural communities and or the workers on farms still use the bush or bucket method when defecating, this together with all the livestock on the farms contribute highly to faecal pollution of water (Ekklesia *et al.* 2015). *E. coli* reside in livestock's intestinal tracts, such as cattle, sheep, goats, pigs and chickens, all of which were seen on the sampled farms. *E. coli* could be spread from one person to another, with contact between these animals and humans and by ingesting it. On these farms the people swam in their open dams potentially spreading *E. coli*, as residents drank from both the open dam system and the closed system e.g. the borehole. Zero *E. coli* or total coliform per 100 ml of sample may be present in drinking water, as stated by WHO (2018). Nico's *E. coli* and total coliform count was much higher than the 0 cfu/00ml (WHO 2018). Laurencia and Laurencia Pos's bacteriological content showed that the water was unfit for human consumption. Studies done by Palamuleni & Akoth (2015), Taonameso *et al.* (2019) in South Africa and Zvidzai *et al*. (2007) in Zimbabwe in areas with approximately the same climate as the Odendaal farms, showed that total coliform and *E. coli* levels of borehole water differed substantially. This difference might be because of infrastructural damage and borehole set up (Lewis & Claasen 2018). All sampled farms' water exceeded 0cfu/100ml and fell in Group D.

5.2. Removal efficiencies, flow rates and relationships between the three filters

Filtration rate is an important factor to be considered in determining the performance of the filter. For daily human activity each person requires 25 L/d of water (DWAF 2002). If a filter cannot meet the minimum daily requirements per human, like the charcoal filter, then an alternative solution might be better. The low filtration rates of the charcoal filter make it inconvenient for users. This slow filtration rate of the charcoal suggests that the filter should rather be used with larger activated charcoal pieces. Using bigger charcoal pieces rather than the fine charcoal that was used could increase the filtration rate accordingly (Dalahmeh *et al*. 2012). The flow rate is also affected by the length of the filtrate column, seeing that all filters had a filtrate column of 25cm, we would assume that their flow rates would be the same, but the different materials in the filters caused different flow rates.

Normally, a higher filtration rate means that the filtrates pore size was larger and so the porosity was high, letting more impurities filter through (Sobsey & Stauber 2008). It is commonly believed that the filtration rate of a filter is inversely related to the removal efficiency of contaminants (Sagara 2000). When reporting on individual filters, it showed that bucket filter 3 and 5, charcoal filter 1,3,4,6 and sand filter 1,3,4,5 and 6 showed complete removal of *E. coli*, but none of the filters showed complete removal of total coliforms. The bucket filter on average had the lowest carbonate hardness and *E .coli* percentage removal efficiencies of the three filters. The charcoal filter was the most efficient filter in removing carbonate hardness from the sampled water (67.7%). The sand filter was the most efficient filter in removing bacteriological (total coliforms and *E. coli*) content from the sampled water. In this study it was clear that turbidity was caused by disturbances of sediments e.g. where the sand moved from the upper bucket to the lower bucket of the bucket filter. None of the filters aided in turbidity removal, this is because holes on the diffuser plates could have been too big on all filters, but it was especially detected on the bucket filter as sand particles were found in the bottom bucket. This may have been one of the reasons why the turbidity levels increased. The borehole's water conductivity for the bucket and the sand filter increased, this could be the result of saline particles in the filtrate (Tutmez *et al.* 2006).

The reason for diminutive removal of physico-chemical and bacteriological content from the filtered water could be because these types of filters have short detention times. These filters use physical mechanisms to trap solids in the pores between their filtrate particles and can only remove particles larger than the spaces between the filtrate particles (Lee 2001). Within these types of filters, removal occurs largely within the filtration bed over a considerable depth. The filters' filtrate depth of this study may have been too shallow to remove some parameters.

All three filters presented that the more they were used the less water they produced, causing a decline in the flow rates. The graphs (Figure 4.15 & 4.16) also showed that from the 1st to 3rd sampling the average flow rates decrease and most of them increase again on the 4th sampling. This decrease could have been caused by the accumulation of dirt and other particles from the filtration water that was stuck in the sedimentation pores of the filters, blocking the pores (Elliott *et al.* 2008). Before the 4th sampling all filters were cleaned, this could be the reason why most filters performed optimally again. An extreme increase in flow rates were seen on the 4th sampling from the bucket and the charcoal filters, while only a slight increase in flow rates was observed from the sand filter.

This study showed that all the filter's flow rates were either weak or moderately related to the removal of its physico-chemical and bacteriological parameters. From the study the charcoal filter had the highest percentage removal efficiency of carbonate hardness, but the charcoal filter had the lowest flow rates between the three filters. The most efficient filter in removing biological content was the sand filter even though it had a flow rate slightly above the limit needed for daily human consumption. The bucket filter had the highest flow rate, but the slightest reduction in physico-chemical content of the water; this is because the porosity of the filtrate was large so water could freely move through the filtrate, but less metabolic breakdown and sedimentation could take place in the filtrate to remove content (Haig *et al*. 2011).

As turbidity increased, the bacterial counts decreased showing that slit, clay and sand particles that are either organic or inorganic particles, contribute to the turbidity of the filtered water, as opposed to the *E. coli* and total coliforms which are small (Simataa 2010).

CHAPTER 6

6. Conclusion

The study revealed that groundwater, which is the main source of drinking water on these farms, is microbiologically not fit for human consumption. The quality of the water is largely attributed to the high levels of nitrate, total coliforms and *E. coli*. The borehole water was contaminated by faecal pollution caused by livestock and unhygienic practices by humans. From 2011 to 2019 in general the pH levels lowered slightly, the carbonate hardness levels decreased as all farms were classified in Group A in 2019, the iron levels increased, except for Nico, because new pipes had been installed and the nitrate levels increased, except for Laurencia.

The study confirms that the selected water filters can improve the quality of contaminated water to a certain extend. Based on the study results, the author can depict the most efficient filter based on the efficient removal of carbonate hardness, total coliforms and *E. coli* from sampled water and the flow rates. The author states that the sand filter proved to be the most efficient filter as it could remove carbonate hardness, total coliforms and *E. coli* from the sampled water and it provided more than 25L of water a day. Even though the filters proved to be efficient in removal of carbonate hardness, total coliforms and *E. coli*, they did not provide water that is of great quality, all filters still provided water that was unfit for human consumption. The study also showed that the physico-chemical and bacteriological content removal and the flow rates were only weak and moderately related. Thus it is not advised that the filters be used as household water treatment devices if further alteration doesn't take place. This study's filters can alternatively be used as a pretreatment filter, before other purification methods are used.

CHAPTER 7

7. Recommendations

Recommendations for physico-chemical and bacteriological water content:

- Relocate livestock far away from the borehole itself, to lessen contamination.
- Livestock pens should be kept at a lower gradient than the borehole, to prevent runoff and draining of animal faeces into groundwater.
- Livestock pens should be kept away from water sources.
- Construct rainfall runoff diversion ditches both up-slope and down-slope of livestock pens and watering points.
- Boreholes should be fenced off about 30m, to prevent animals from causing more contamination.
- Keep pumps and any other borehole equipment off the ground when being repaired, as contamination of bacteria can happen on the ground.
- Laying underground poly vinyl chloride water pipes, as above ground pipes get stepped on by livestock and when they break, contamination takes place.
- Using the otji-toilets instead of the bush or bucket method, as the construction of these dry sanitation systems will not only prevent contaminants from entering the groundwater, but will also improve community hygiene.
- Testing infrastructure at point of consumption can be tested to determine if the infrastructure could have contributed to contamination.
- Educational workshops and awareness programs on behaviours to prevent water contamination.

- A monitoring and evaluation water quality programme needs to be developed for these farms.

Recommendations for filters:

- As the Charcoal filter removed most carbonate hardness, but had the lowest flow rates, using activated charcoal with larger particle sizes could increase the flow rate or adding coconut shell activated carbon, as seen from other studies, could help to increase the flow rates as coconut shell activated carbon is very aggressive in adsorbing chemicals, and thus the flow rate will increase.
- This study showed that there was a design implementation problem with the bucket filter, as water leaked out between the two buckets; it is recommended that the bottom buckets lid is cut so that the top bucket fits in the hole, rather than using glue.
- Another design implementation problem was the holes in the diffusion plates were too big and filtrate dripped down from the top bucket to the bottom bucket. It is recommended that the holes must be smaller especially for the bucket filter, to avoid filtrate from seeping through.
- All three filters showed that the filtration process cannot treat the water to a consumable state for humans as recommended by WHO (2018) and ALS cc, although all filters showed improvement of water quality. Adding chlorine after filtering could kill more bacteria in the water, although chlorine that is suitable for drinking water disinfection is not readily available at household level in Namibia.

- Another alternative could be boiling of the water after filtering to produce water of high quality. Boiling must be used after filtering despite its cost, inconvenience and environmental impact.
- The filtrate depth could also be increased from 25cm to 35cm remove more of the contaminated water content.
- Conduct research on the social and cultural acceptability of these three filters, so that they can be implemented in reality.

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9. Appendices

APPENDIX 1

Table 9.1. Cost of constructing the filters.

Material	**Cost (N$) per item**	**Quantity**	**Total cost (N$)**
Buckets 25L	120	18	2160
Buckets 20L	72.95	6	43.70
Funnels	45	6	270
Tap	50	18	900
Fine sand 50kg	85	3	255
Coarse sand 50kg	80	3	240
Gravel 20kg	61.30	4	245.20
Activated charcoal 100g	29.95	20	599
Cloth 1m	48	1m	48
Total			**4760.90**

APPENDIX 2

The statistical analysis of the study.

Table 9.2. Normality testing using Shapiro-Wilk.

<table>
<tr><th>Parameter</th><th>Test</th></tr>
<tr><td>Borehole water
(before filtering)</td><td>
Tests of Normality
<table>
<tr><th></th><th>Shapiro-Wilk</th><th></th><th></th><th></th></tr>
<tr><th></th><th>Statistic</th><th>Statistic</th><th>df</th><th>Sig.</th></tr>
<tr><td>Ph</td><td>.271</td><td>.810</td><td>15</td><td>.005</td></tr>
<tr><td>Turbidity</td><td>.238</td><td>.819</td><td>15</td><td>.006</td></tr>
<tr><td>Conductivity</td><td>.239</td><td>.855</td><td>15</td><td>.021</td></tr>
<tr><td>Hardness</td><td>.263</td><td>.749</td><td>15</td><td>.001</td></tr>
</table>
<table>
<tr><th></th><th>Shapiro-Wilk</th><th></th><th></th></tr>
<tr><th></th><th>Statistic</th><th>df</th><th>Sig.</th></tr>
<tr><td>NITRATE</td><td>.935</td><td>15</td><td>.329</td></tr>
<tr><td>PHOSPHATE</td><td>.780</td><td>15</td><td>.002</td></tr>
<tr><td>IRON</td><td>.713</td><td>15</td><td>.000</td></tr>
<tr><td>COPPER</td><td>.826</td><td>15</td><td>.008</td></tr>
<tr><td>ZINC</td><td>.703</td><td>15</td><td>.000</td></tr>
</table>
<table>
<tr><th></th><th>Shapiro-Wilk</th><th></th><th></th></tr>
<tr><th></th><th>Statistic</th><th>df</th><th>Sig.</th></tr>
<tr><td>coliforms</td><td>.739</td><td>23</td><td>.000</td></tr>
<tr><td>e.coli</td><td>.861</td><td>23</td><td>.004</td></tr>
</table>
</td></tr>
<tr><td>Removal data</td><td>
Tests of Normality
<table>
<tr><th></th><th colspan="3">Shapiro-Wilk</th></tr>
<tr><th></th><th>Statistic</th><th>df</th><th>Sig.</th></tr>
<tr><td>Ph</td><td>.957</td><td>33</td><td>.215</td></tr>
<tr><td>Turbidity</td><td>.940</td><td>33</td><td>.066</td></tr>
<tr><td>conductivity</td><td>.926</td><td>33</td><td>.026</td></tr>
<tr><td>Hardness</td><td>.944</td><td>33</td><td>.091</td></tr>
<tr><td>Nitrate</td><td>.958</td><td>33</td><td>.231</td></tr>
<tr><td>Phosphate</td><td>.879</td><td>33</td><td>.002</td></tr>
<tr><td>Iron</td><td>.671</td><td>33</td><td>.000</td></tr>
<tr><td>Copper</td><td>.685</td><td>33</td><td>.000</td></tr>
<tr><td>Zinc</td><td>.635</td><td>33</td><td>.000</td></tr>
</table>
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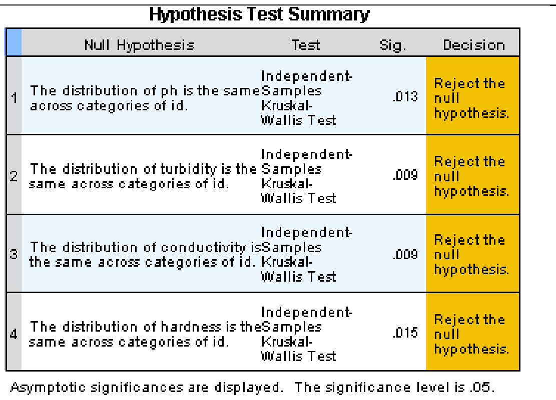
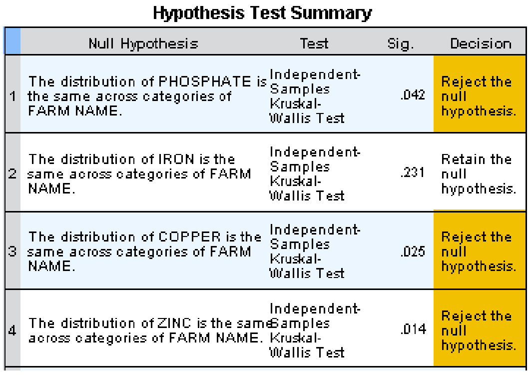
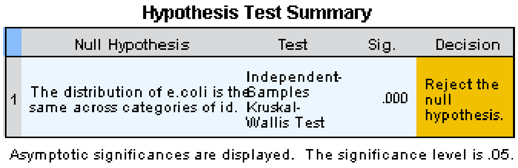
</table>

<table>
<tr>
<td></td>
<td>
Tests of Normality
<table>
<tr><th></th><th colspan="3">Shapiro-Wilk</th></tr>
<tr><th></th><th>Statistic</th><th>df</th><th>Sig.</th></tr>
<tr><td>Coliforms</td><td>.807</td><td>42</td><td>.000</td></tr>
<tr><td>e.coli</td><td>.722</td><td>42</td><td>.000</td></tr>
</table>
</td>
</tr>
<tr>
<td>Borehole water

(after filtering)</td>
<td>
Tests of Normality
<table>
<tr><th></th><th colspan="3">Shapiro-Wilk</th></tr>
<tr><th></th><th>Statistic</th><th>df</th><th>Sig.</th></tr>
<tr><td>CARBONATE HARDNESS</td><td>.930</td><td>72</td><td>.001</td></tr>
<tr><td>TURBIDITY</td><td>.773</td><td>72</td><td>.000</td></tr>
<tr><td>PH</td><td>.897</td><td>72</td><td>.000</td></tr>
<tr><td>CONDUCTIVITY</td><td>.905</td><td>72</td><td>.000</td></tr>
</table>
Tests of Normality
<table>
<tr><th></th><th colspan="3">Shapiro-Wilk</th></tr>
<tr><th></th><th>Statistic</th><th>df</th><th>Sig.</th></tr>
<tr><td>NITRATE</td><td>.909</td><td>54</td><td>.001</td></tr>
<tr><td>PHOSPHATE</td><td>.895</td><td>54</td><td>.000</td></tr>
<tr><td>IRON</td><td>.686</td><td>54</td><td>.000</td></tr>
<tr><td>ZINC</td><td>.470</td><td>54</td><td>.000</td></tr>
<tr><td>COPPER</td><td>.760</td><td>54</td><td>.000</td></tr>
</table>
Tests of Normality
<table>
<tr><th></th><th colspan="3">Shapiro-Wilk</th></tr>
<tr><th></th><th>Statistic</th><th>df</th><th>Sig.</th></tr>
<tr><td>Coliforms</td><td>.785</td><td>53</td><td>.000</td></tr>
<tr><td>e.coli</td><td>.461</td><td>53</td><td>.000</td></tr>
</table>
</td>
</tr>
<tr>
<td>Flowrates</td>
<td>
Tests of Normality
<table>
<tr><th></th><th colspan="3">Kolmogorov-Smirnov[a]</th><th colspan="3">Shapiro-Wilk</th></tr>
<tr><th></th><th>Statistic</th><th>df</th><th>Sig.</th><th>Statistic</th><th>df</th><th>Sig.</th></tr>
<tr><td>flowrates</td><td>.180</td><td>72</td><td>.000</td><td>.884</td><td>72</td><td>.000</td></tr>
</table>
</td>
</tr>
</table>

Table 9.3. Kruskal-Wallis Test for comparing means.

<table>
<tr><th>Parameter</th><th>Test</th></tr>
<tr><td>pH
Turbidity
Conductivity
Carbonate hardness
(borehole water)</td><td>
Hypothesis Test Summary
<table>
<tr><th></th><th>Null Hypothesis</th><th>Test</th><th>Sig.</th><th>Decision</th></tr>
<tr><td>1</td><td>The distribution of ph is the same across categories of id.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.013</td><td>Reject the null hypothesis.</td></tr>
<tr><td>2</td><td>The distribution of turbidity is the same across categories of id.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.009</td><td>Reject the null hypothesis.</td></tr>
<tr><td>3</td><td>The distribution of conductivity is the same across categories of id.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.009</td><td>Reject the null hypothesis.</td></tr>
<tr><td>4</td><td>The distribution of hardness is the same across categories of id.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.015</td><td>Reject the null hypothesis.</td></tr>
</table>
Asymptotic significances are displayed. The significance level is .05.</td></tr>
<tr><td>Phosphate
Iron
Copper
Zinc
Free chlorine
Total chlorine
(borehole water)</td><td>
Hypothesis Test Summary
<table>
<tr><th></th><th>Null Hypothesis</th><th>Test</th><th>Sig.</th><th>Decision</th></tr>
<tr><td>1</td><td>The distribution of PHOSPHATE is the same across categories of FARM NAME.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.042</td><td>Reject the null hypothesis.</td></tr>
<tr><td>2</td><td>The distribution of IRON is the same across categories of FARM NAME.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.231</td><td>Retain the null hypothesis.</td></tr>
<tr><td>3</td><td>The distribution of COPPER is the same across categories of FARM NAME.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.025</td><td>Reject the null hypothesis.</td></tr>
<tr><td>4</td><td>The distribution of ZINC is the same across categories of FARM NAME.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.014</td><td>Reject the null hypothesis.</td></tr>
</table></td></tr>
<tr><td><i>E.coli</i>
(borehole water)</td><td>
Hypothesis Test Summary
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<tr><th></th><th>Null Hypothesis</th><th>Test</th><th>Sig.</th><th>Decision</th></tr>
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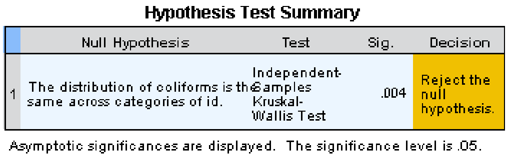
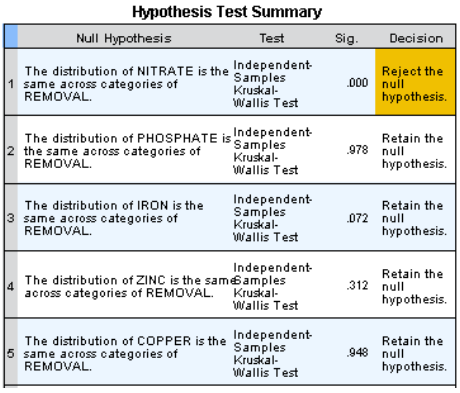
</table>
Asymptotic significances are displayed. The significance level is .05.</td></tr>
<tr><td>Total coliforms
(borehole water)</td><td>
Hypothesis Test Summary
<table>
<tr><th></th><th>Null Hypothesis</th><th>Test</th><th>Sig.</th><th>Decision</th></tr>
<tr><td>1</td><td>The distribution of coliforms is the same across categories of id.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.004</td><td>Reject the null hypothesis.</td></tr>
</table>
Asymptotic significances are displayed. The significance level is .05.</td></tr>
</table>

<table>
<tr>
<td>Nitrate
Phosphate
Iron
Zinc
Copper
(after filtering)</td>
<td>

Hypothesis Test Summary
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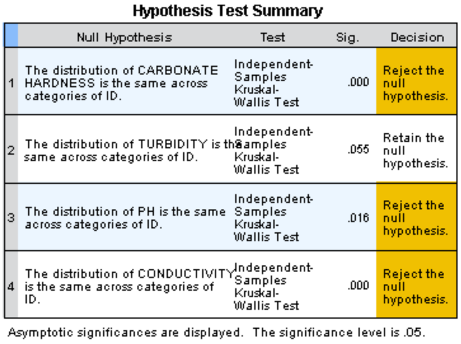
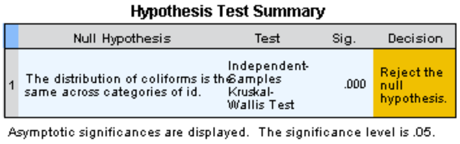
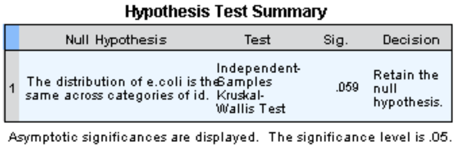
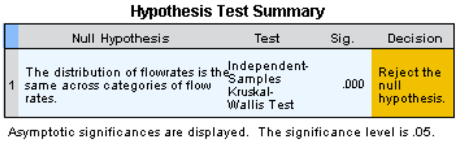
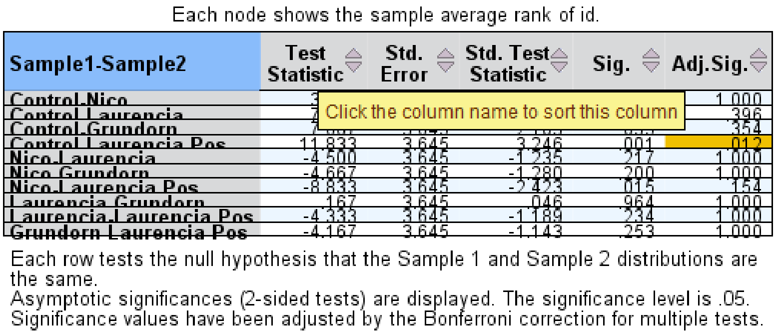
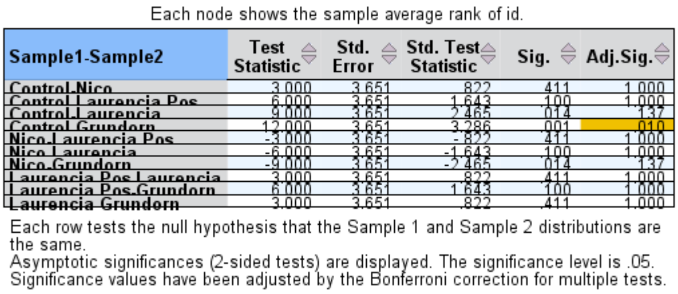
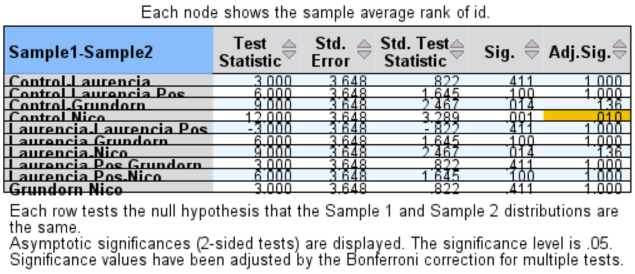
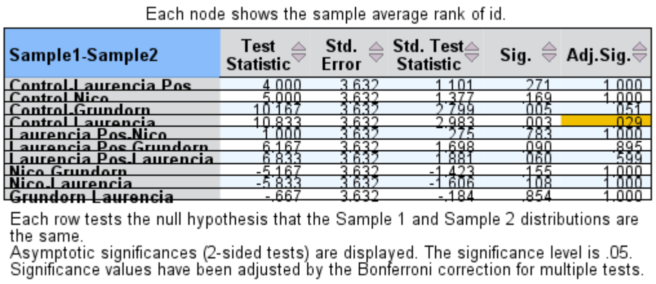
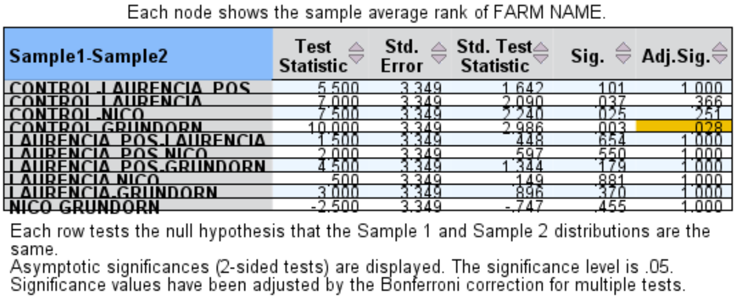
<tr><th></th><th>Null Hypothesis</th><th>Test</th><th>Sig.</th><th>Decision</th></tr>
<tr><td>1</td><td>The distribution of NITRATE is the same across categories of REMOVAL.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.000</td><td>Reject the null hypothesis.</td></tr>
<tr><td>2</td><td>The distribution of PHOSPHATE is the same across categories of REMOVAL.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.978</td><td>Retain the null hypothesis.</td></tr>
<tr><td>3</td><td>The distribution of IRON is the same across categories of REMOVAL.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.072</td><td>Retain the null hypothesis.</td></tr>
<tr><td>4</td><td>The distribution of ZINC is the same across categories of REMOVAL.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.312</td><td>Retain the null hypothesis.</td></tr>
<tr><td>5</td><td>The distribution of COPPER is the same across categories of REMOVAL.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.948</td><td>Retain the null hypothesis.</td></tr>
</table>
</td>
</tr>
<tr>
<td>Carbonate hardness
Turbidity
pH
Conductivity
(after filtering)</td>
<td>

Hypothesis Test Summary
<table>
<tr><th></th><th>Null Hypothesis</th><th>Test</th><th>Sig.</th><th>Decision</th></tr>
<tr><td>1</td><td>The distribution of CARBONATE HARDNESS is the same across categories of ID.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.000</td><td>Reject the null hypothesis.</td></tr>
<tr><td>2</td><td>The distribution of TURBIDITY is the same across categories of ID.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.055</td><td>Retain the null hypothesis.</td></tr>
<tr><td>3</td><td>The distribution of PH is the same across categories of ID.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.016</td><td>Reject the null hypothesis.</td></tr>
<tr><td>4</td><td>The distribution of CONDUCTIVITY is the same across categories of ID.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.000</td><td>Reject the null hypothesis.</td></tr>
</table>
Asymptotic significances are displayed. The significance level is .05.
</td>
</tr>
<tr>
<td>Coliforms
(after filtering)</td>
<td>

Hypothesis Test Summary
<table>
<tr><th></th><th>Null Hypothesis</th><th>Test</th><th>Sig.</th><th>Decision</th></tr>
<tr><td>1</td><td>The distribution of coliforms is the same across categories of id.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.000</td><td>Reject the null hypothesis.</td></tr>
</table>
Asymptotic significances are displayed. The significance level is .05.
</td>
</tr>
<tr>
<td><i>E.coli</i>
(after filtering)</td>
<td>

Hypothesis Test Summary
<table>
<tr><th></th><th>Null Hypothesis</th><th>Test</th><th>Sig.</th><th>Decision</th></tr>
<tr><td>1</td><td>The distribution of e.coli is the same across categories of id.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.059</td><td>Retain the null hypothesis.</td></tr>
</table>
Asymptotic significances are displayed. The significance level is .05.
</td>
</tr>
<tr>
<td>Flowrates</td>
<td>

Hypothesis Test Summary
<table>
<tr><th></th><th>Null Hypothesis</th><th>Test</th><th>Sig.</th><th>Decision</th></tr>
<tr><td>1</td><td>The distribution of flowrates is the same across categories of flow rates.</td><td>Independent-Samples Kruskal-Wallis Test</td><td>.000</td><td>Reject the null hypothesis.</td></tr>
</table>
Asymptotic significances are displayed. The significance level is .05.
</td>
</tr>
</table>

Table 9.4. Bonferroni correction to observe where the difference was.

<table>
<tr><th>Parameter</th><th>Test</th></tr>
<tr><td>pH</td><td>


Each node shows the sample average rank of id.
<table>
<tr><th>Sample1-Sample2</th><th>Test Statistic</th><th>Std. Error</th><th>Std. Test Statistic</th><th>Sig.</th><th>Adj.Sig.</th></tr>
<tr><td>Control-Nico</td><td>[illegible]</td><td>[illegible]</td><td>[illegible]</td><td>[illegible]</td><td>1.000</td></tr>
<tr><td>Control-Laurencia</td><td>[illegible]</td><td>[illegible]</td><td>[illegible]</td><td>[illegible]</td><td>.396</td></tr>
<tr><td>Control-Grundorn</td><td>[illegible]</td><td>[illegible]</td><td>[illegible]</td><td>[illegible]</td><td>.354</td></tr>
<tr><td>Control-Laurencia Pos</td><td>11.833</td><td>3.645</td><td>3.246</td><td>.001</td><td>.012</td></tr>
<tr><td>Nico-Laurencia</td><td>-4.500</td><td>3.645</td><td>-1.235</td><td>.217</td><td>1.000</td></tr>
<tr><td>Nico-Grundorn</td><td>-4.667</td><td>3.645</td><td>-1.280</td><td>.200</td><td>1.000</td></tr>
<tr><td>Nico-Laurencia Pos</td><td>-8.833</td><td>3.645</td><td>-2.423</td><td>.015</td><td>.154</td></tr>
<tr><td>Laurencia-Grundorn</td><td>.167</td><td>3.645</td><td>.046</td><td>.964</td><td>1.000</td></tr>
<tr><td>Laurencia-Laurencia Pos</td><td>-4.333</td><td>3.645</td><td>-1.189</td><td>.234</td><td>1.000</td></tr>
<tr><td>Grundorn-Laurencia Pos</td><td>-4.167</td><td>3.645</td><td>-1.143</td><td>.253</td><td>1.000</td></tr>
</table>
Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.
Significance values have been adjusted by the Bonferroni correction for multiple tests.
</td></tr>
<tr><td>turbidity</td><td>

Each node shows the sample average rank of id.
<table>
<tr><th>Sample1-Sample2</th><th>Test Statistic</th><th>Std. Error</th><th>Std. Test Statistic</th><th>Sig.</th><th>Adj.Sig.</th></tr>
<tr><td>Control-Nico</td><td>3.000</td><td>3.651</td><td>.822</td><td>.411</td><td>1.000</td></tr>
<tr><td>Control-Laurencia Pos</td><td>6.000</td><td>3.651</td><td>1.643</td><td>.100</td><td>1.000</td></tr>
<tr><td>Control-Laurencia</td><td>9.000</td><td>3.651</td><td>2.465</td><td>.014</td><td>.137</td></tr>
<tr><td>Control-Grundorn</td><td>12.000</td><td>3.651</td><td>3.286</td><td>.001</td><td>.010</td></tr>
<tr><td>Nico-Laurencia Pos</td><td>-3.000</td><td>3.651</td><td>-.822</td><td>.411</td><td>1.000</td></tr>
<tr><td>Nico-Laurencia</td><td>-6.000</td><td>3.651</td><td>-1.643</td><td>.100</td><td>1.000</td></tr>
<tr><td>Nico-Grundorn</td><td>-9.000</td><td>3.651</td><td>-2.465</td><td>.014</td><td>.137</td></tr>
<tr><td>Laurencia Pos-Laurencia</td><td>3.000</td><td>3.651</td><td>.822</td><td>.411</td><td>1.000</td></tr>
<tr><td>Laurencia Pos-Grundorn</td><td>6.000</td><td>3.651</td><td>1.643</td><td>.100</td><td>1.000</td></tr>
<tr><td>Laurencia-Grundorn</td><td>3.000</td><td>3.651</td><td>.822</td><td>.411</td><td>1.000</td></tr>
</table>
Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.
Significance values have been adjusted by the Bonferroni correction for multiple tests.
</td></tr>
<tr><td>conductivity</td><td>

Each node shows the sample average rank of id.
<table>
<tr><th>Sample1-Sample2</th><th>Test Statistic</th><th>Std. Error</th><th>Std. Test Statistic</th><th>Sig.</th><th>Adj.Sig.</th></tr>
<tr><td>Control-Laurencia</td><td>3.000</td><td>3.648</td><td>.822</td><td>.411</td><td>1.000</td></tr>
<tr><td>Control-Laurencia Pos</td><td>6.000</td><td>3.648</td><td>1.645</td><td>.100</td><td>1.000</td></tr>
<tr><td>Control-Grundorn</td><td>9.000</td><td>3.648</td><td>2.467</td><td>.014</td><td>.136</td></tr>
<tr><td>Control-Nico</td><td>12.000</td><td>3.648</td><td>3.289</td><td>.001</td><td>.010</td></tr>
<tr><td>Laurencia-Laurencia Pos</td><td>-3.000</td><td>3.648</td><td>-.822</td><td>.411</td><td>1.000</td></tr>
<tr><td>Laurencia-Grundorn</td><td>6.000</td><td>3.648</td><td>1.645</td><td>.100</td><td>1.000</td></tr>
<tr><td>Laurencia-Nico</td><td>9.000</td><td>3.648</td><td>2.467</td><td>.014</td><td>.136</td></tr>
<tr><td>Laurencia Pos-Grundorn</td><td>3.000</td><td>3.648</td><td>.822</td><td>.411</td><td>1.000</td></tr>
<tr><td>Laurencia Pos-Nico</td><td>6.000</td><td>3.648</td><td>1.645</td><td>.100</td><td>1.000</td></tr>
<tr><td>Grundorn-Nico</td><td>3.000</td><td>3.648</td><td>.822</td><td>.411</td><td>1.000</td></tr>
</table>
Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.
Significance values have been adjusted by the Bonferroni correction for multiple tests.
</td></tr>
<tr><td>hardness</td><td>

Each node shows the sample average rank of id.
<table>
<tr><th>Sample1-Sample2</th><th>Test Statistic</th><th>Std. Error</th><th>Std. Test Statistic</th><th>Sig.</th><th>Adj.Sig.</th></tr>
<tr><td>Control-Laurencia Pos</td><td>4.000</td><td>3.632</td><td>1.101</td><td>.271</td><td>1.000</td></tr>
<tr><td>Control-Nico</td><td>5.000</td><td>3.632</td><td>1.377</td><td>.169</td><td>1.000</td></tr>
<tr><td>Control-Grundorn</td><td>10.167</td><td>3.632</td><td>2.799</td><td>.005</td><td>.051</td></tr>
<tr><td>Control-Laurencia</td><td>10.833</td><td>3.632</td><td>2.983</td><td>.003</td><td>.029</td></tr>
<tr><td>Laurencia Pos-Nico</td><td>1.000</td><td>3.632</td><td>.275</td><td>.783</td><td>1.000</td></tr>
<tr><td>Laurencia Pos-Grundorn</td><td>6.167</td><td>3.632</td><td>1.698</td><td>.090</td><td>.895</td></tr>
<tr><td>Laurencia Pos-Laurencia</td><td>6.833</td><td>3.632</td><td>1.881</td><td>.060</td><td>.599</td></tr>
<tr><td>Nico-Grundorn</td><td>-5.167</td><td>3.632</td><td>-1.423</td><td>.155</td><td>1.000</td></tr>
<tr><td>Nico-Laurencia</td><td>-5.833</td><td>3.632</td><td>-1.606</td><td>.108</td><td>1.000</td></tr>
<tr><td>Grundorn-Laurencia</td><td>-.667</td><td>3.632</td><td>-.184</td><td>.854</td><td>1.000</td></tr>
</table>
Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.
Significance values have been adjusted by the Bonferroni correction for multiple tests.
</td></tr>
</table>

phosphate

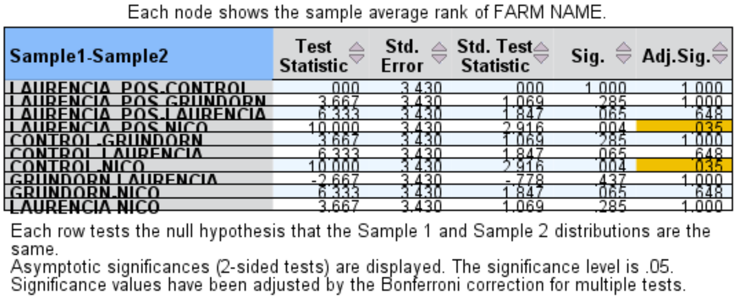


Each node shows the sample average rank of FARM NAME.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
CONTROL-LAURENCIA_POS	5.500	3.349	1.642	.101	1.000
CONTROL-LAURENCIA	7.000	3.349	2.090	.037	.366
CONTROL-NICO	7.500	3.349	2.240	.025	.251
CONTROL-GRUNDORN	10.000	3.349	2.986	.003	.028
LAURENCIA_POS-LAURENCIA	1.500	3.349	.448	.654	1.000
LAURENCIA_POS-NICO	2.000	3.349	.597	.550	1.000
LAURENCIA_POS-GRUNDORN	4.500	3.349	1.344	.179	1.000
LAURENCIA-NICO	.500	3.349	.149	.881	1.000
LAURENCIA-GRUNDORN	3.000	3.349	.896	.370	1.000
NICO-GRUNDORN	-2.500	3.349	-.747	.455	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.
Significance values have been adjusted by the Bonferroni correction for multiple tests.

Zinc

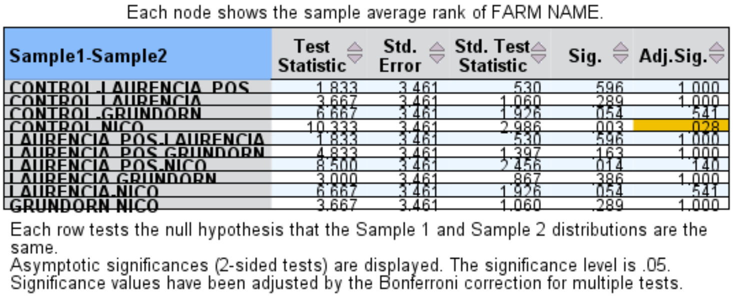


Each node shows the sample average rank of FARM NAME.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
LAURENCIA_POS-CONTROL	.000	3.430	.000	1.000	1.000
LAURENCIA_POS-GRUNDORN	3.667	3.430	1.069	.285	1.000
LAURENCIA_POS-LAURENCIA	6.333	3.430	1.847	.065	.648
LAURENCIA_POS-NICO	10.000	3.430	2.916	.004	.035
CONTROL-GRUNDORN	3.667	3.430	1.069	.285	1.000
CONTROL-LAURENCIA	6.333	3.430	1.847	.065	.648
CONTROL-NICO	10.000	3.430	2.916	.004	.035
GRUNDORN-LAURENCIA	-2.667	3.430	-.778	.437	1.000
GRUNDORN-NICO	6.333	3.430	1.847	.065	.648
LAURENCIA-NICO	3.667	3.430	1.069	.285	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.
Significance values have been adjusted by the Bonferroni correction for multiple tests.

copper

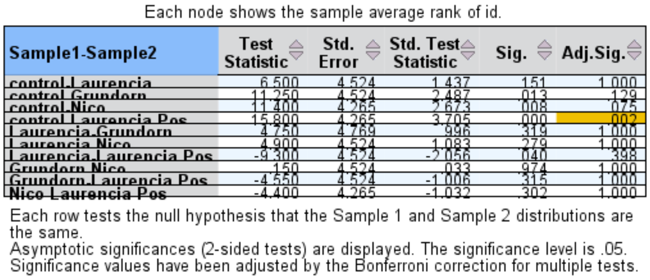


Each node shows the sample average rank of FARM NAME.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
CONTROL-LAURENCIA_POS	1.833	3.461	.530	.596	1.000
CONTROL-LAURENCIA	3.667	3.461	1.060	.289	1.000
CONTROL-GRUNDORN	6.667	3.461	1.926	.054	.541
CONTROL-NICO	10.333	3.461	2.986	.003	.028
LAURENCIA_POS-LAURENCIA	1.833	3.461	.530	.596	1.000
LAURENCIA_POS-GRUNDORN	4.833	3.461	1.397	.163	1.000
LAURENCIA_POS-NICO	8.500	3.461	2.456	.014	.140
LAURENCIA-GRUNDORN	3.000	3.461	.867	.386	1.000
LAURENCIA-NICO	6.667	3.461	1.926	.054	.541
GRUNDORN-NICO	3.667	3.461	1.060	.289	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.
Significance values have been adjusted by the Bonferroni correction for multiple tests.

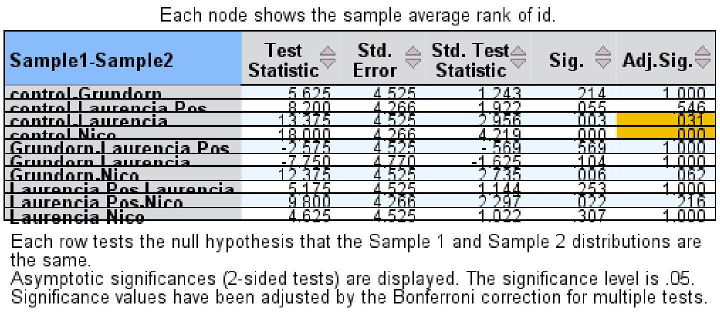
total coliforms



Each node shows the sample average rank of id.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
control-Laurencia	6.500	4.524	1.437	.151	1.000
control-Grundorn	11.250	4.524	2.487	.013	.129
control-Nico	11.400	4.265	2.673	.008	.075
control-Laurencia Pos	15.800	4.265	3.705	.000	.002
Laurencia-Grundorn	4.750	4.769	.996	.319	1.000
Laurencia-Nico	4.900	4.524	1.083	.279	1.000
Laurencia-Laurencia Pos	-9.300	4.524	-2.056	.040	.398
Grundorn-Nico	.150	4.524	.033	.974	1.000
Grundorn-Laurencia Pos	-4.550	4.524	-1.006	.315	1.000
Nico-Laurencia Pos	-4.400	4.265	-1.032	.302	1.000

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.
Significance values have been adjusted by the Bonferroni correction for multiple tests.

<table>
<tr><td><i>E. coli</i></td><td>

Each node shows the sample average rank of id.
<table>
<tr><th>Sample1-Sample2</th><th>Test Statistic</th><th>Std. Error</th><th>Std. Test Statistic</th><th>Sig.</th><th>Adj.Sig.</th></tr>
<tr><td>control-Grundorn</td><td>5.625</td><td>4.525</td><td>1.243</td><td>.214</td><td>1.000</td></tr>
<tr><td>control-Laurencia Pos</td><td>8.200</td><td>4.266</td><td>1.922</td><td>.055</td><td>.546</td></tr>
<tr><td>control-Laurencia</td><td>13.375</td><td>4.525</td><td>2.956</td><td>.003</td><td>.031</td></tr>
<tr><td>control-Nico</td><td>18.000</td><td>4.266</td><td>4.219</td><td>.000</td><td>.000</td></tr>
<tr><td>Grundorn-Laurencia Pos</td><td>-2.575</td><td>4.525</td><td>-.569</td><td>.569</td><td>1.000</td></tr>
<tr><td>Grundorn-Laurencia</td><td>-7.750</td><td>4.770</td><td>-1.625</td><td>.104</td><td>1.000</td></tr>
<tr><td>Grundorn-Nico</td><td>12.375</td><td>4.525</td><td>2.735</td><td>.006</td><td>.062</td></tr>
<tr><td>Laurencia Pos-Laurencia</td><td>5.175</td><td>4.525</td><td>1.144</td><td>.253</td><td>1.000</td></tr>
<tr><td>Laurencia Pos-Nico</td><td>9.800</td><td>4.266</td><td>2.297</td><td>.022</td><td>.216</td></tr>
<tr><td>Laurencia-Nico</td><td>4.625</td><td>4.525</td><td>1.022</td><td>.307</td><td>1.000</td></tr>
</table>
Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.
Significance values have been adjusted by the Bonferroni correction for multiple tests.
</td></tr>
<tr><td>Total coliforms

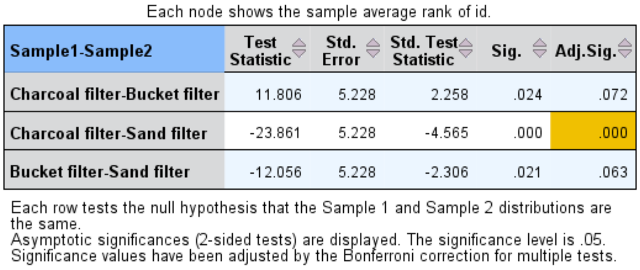
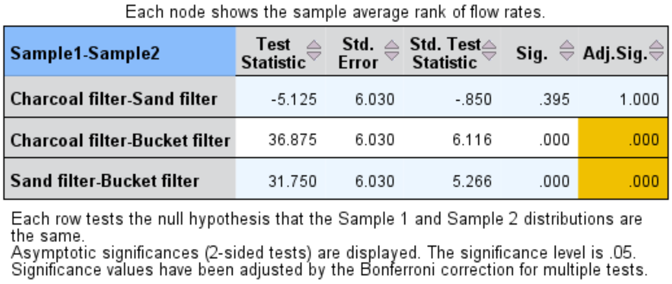
(after filtering)</td><td>

Each node shows the sample average rank of id.
<table>
<tr><th>Sample1-Sample2</th><th>Test Statistic</th><th>Std. Error</th><th>Std. Test Statistic</th><th>Sig.</th><th>Adj.Sig.</th></tr>
<tr><td>Charcoal filter-Bucket filter</td><td>11.806</td><td>5.228</td><td>2.258</td><td>.024</td><td>.072</td></tr>
<tr><td>Charcoal filter-Sand filter</td><td>-23.861</td><td>5.228</td><td>-4.565</td><td>.000</td><td>.000</td></tr>
<tr><td>Bucket filter-Sand filter</td><td>-12.056</td><td>5.228</td><td>-2.306</td><td>.021</td><td>.063</td></tr>
</table>
Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.
Significance values have been adjusted by the Bonferroni correction for multiple tests.
</td></tr>
<tr><td>Flowrates</td><td>

Each node shows the sample average rank of flow rates.
<table>
<tr><th>Sample1-Sample2</th><th>Test Statistic</th><th>Std. Error</th><th>Std. Test Statistic</th><th>Sig.</th><th>Adj.Sig.</th></tr>
<tr><td>Charcoal filter-Sand filter</td><td>-5.125</td><td>6.030</td><td>-.850</td><td>.395</td><td>1.000</td></tr>
<tr><td>Charcoal filter-Bucket filter</td><td>36.875</td><td>6.030</td><td>6.116</td><td>.000</td><td>.000</td></tr>
<tr><td>Sand filter-Bucket filter</td><td>31.750</td><td>6.030</td><td>5.266</td><td>.000</td><td>.000</td></tr>
</table>
Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.
Significance values have been adjusted by the Bonferroni correction for multiple tests.
</td></tr>
</table>

Table 9.5. Tukey HSD to observe where the difference is.

Nitrate

Multiple Comparisons

Dependent Variable: NITRATE

Tukey HSD

(I) FARM NAME	(J) FARM NAME	Mean Difference (I-J)	Std. Error	Sig.
nico	grundorn	15.3333*	1.93218	.000
	laurencia	27.6667*	1.93218	.000
	laurencia_pos	33.3333*	1.93218	.000
	control	55.6667*	1.93218	.000
grundorn	nico	-15.3333*	1.93218	.000
	laurencia	12.3333*	1.93218	.001
	laurencia_pos	18.0000*	1.93218	.000
	control	40.3333*	1.93218	.000
laurencia	nico	-27.6667*	1.93218	.000
	grundorn	-12.3333*	1.93218	.001
	laurencia_pos	5.6667	1.93218	.087
	control	28.0000*	1.93218	.000
laurencia_pos	nico	-33.3333*	1.93218	.000
	grundorn	-18.0000*	1.93218	.000
	laurencia	-5.6667	1.93218	.087
	control	22.3333*	1.93218	.000
control	nico	-55.6667*	1.93218	.000
	grundorn	-40.3333*	1.93218	.000
	laurencia	-28.0000*	1.93218	.000
	laurencia_pos	-22.3333*	1.93218	.000

Based on observed means.

The error term is Mean Square(Error) = 5.600.

*. The mean difference is significant at the .05 level.

Table 9.6. One Way ANOVA to compare means.

Nitrate

ANOVA

NITRATE

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5176.933	4	1294.233	231.113	.000
Within Groups	56.000	10	5.600		
Total	5232.933	14			

Table 9.7. Mann-Whitney U test for comparing means.

<table>
<tr>
<td><i>E.coli</i> and total coliforms</td>
<td>
Test Statistics[a]
<table>
<tr><th></th><th>coliforms</th><th>e.coli</th></tr>
<tr><td>Mann-Whitney U</td><td>96.000</td><td>90.500</td></tr>
<tr><td>Wilcoxon W</td><td>286.000</td><td>280.500</td></tr>
<tr><td>Z</td><td>-3.099</td><td>-3.257</td></tr>
<tr><td>Asymp. Sig. (2-tailed)</td><td>.002</td><td>.001</td></tr>
</table>
</td>
</tr>
<tr>
<td>Conductivity
Phosphate
Iron
Copper
Zinc</td>
<td>
Test Statistics[a]
<table>
<tr><th></th><th>Conductivity</th><th>Phosphate</th><th>iron</th><th>copper</th><th>zinc</th></tr>
<tr><td>Mann-Whitney U</td><td>96.5</td><td>86</td><td>114</td><td>102</td><td>127</td></tr>
<tr><td>Wilcoxon W</td><td>216.5</td><td>257</td><td>234</td><td>273</td><td>247</td></tr>
<tr><td>Z</td><td>-1.392</td><td>-1.798</td><td>-.763</td><td>-1.209</td><td>-.291</td></tr>
<tr><td>Asymp. Sig. (2-tailed)</td><td>.164</td><td>.072</td><td>.445</td><td>.227</td><td>.771</td></tr>
<tr><td>Exact Sig. [2*(1-tailed Sig.)]</td><td>.166[b]</td><td>.079[b]</td><td>.464[b]</td><td>.244[b]</td><td>.789[b]</td></tr>
</table>
a. Grouping Variable: ID
b. Not corrected for ties.
</td>
</tr>
</table>

Table 9.8. Independent samples T test for comparing means.

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
hardness	Equal variances assumed	5.133	.031	2.846	31	.008	7.98148	2.80474
	Equal variances not assumed			2.674	18.735	.015	7.98148	2.98458

ph	Equal variances assumed	.278	.602	-.738	31	.466	-.05926	.08032
	Equal variances not assumed			-.737	29.820	.467	-.05926	.08039
turbidity	Equal variances assumed	.892	.352	-3.912	31	.000	-1.25612	.32111
	Equal variances not assumed			-3.818	25.958	.001	-1.25612	.32902
nitrate	Equal variances assumed	7.878	.009	2.025	31	.052	10.17407	5.02363
	Equal variances not assumed			1.898	18.265	.074	10.17407	5.36059

Table 9.9. Spearman correlation between flow rates and physico-chemical and biological removal parameters.

<table>
<tr><td>pH</td><td>correlations
<table>
<tr><td></td><td></td><td></td><td>flowrates</td><td>ph</td></tr>
<tr><td>spearman's rho</td><td>flowrates</td><td>correlation coefficient</td><td>1.000</td><td>-.113</td></tr>
<tr><td></td><td></td><td>sig. (2-tailed)</td><td>.</td><td>.345</td></tr>
<tr><td></td><td></td><td>n</td><td>72</td><td>72</td></tr>
<tr><td></td><td>ph</td><td>correlation coefficient</td><td>-.113</td><td>1.000</td></tr>
<tr><td></td><td></td><td>sig. (2-tailed)</td><td>.345</td><td>.</td></tr>
<tr><td></td><td></td><td>n</td><td>72</td><td>72</td></tr>
</table></td></tr>
<tr><td>Conductivity</td><td>correlations
<table>
<tr><td></td><td></td><td></td><td>flowrates</td><td>conductivity</td></tr>
<tr><td>spearman's rho</td><td>flowrates</td><td>correlation coefficient</td><td>1.000</td><td>-.099</td></tr>
<tr><td></td><td></td><td>sig. (2-tailed)</td><td>.</td><td>.409</td></tr>
<tr><td></td><td></td><td>n</td><td>72</td><td>72</td></tr>
<tr><td></td><td>conductivity</td><td>correlation coefficient</td><td>-.099</td><td>1.000</td></tr>
<tr><td></td><td></td><td>sig. (2-tailed)</td><td>.409</td><td>.</td></tr>
<tr><td></td><td></td><td>n</td><td>72</td><td>72</td></tr>
</table></td></tr>
<tr><td>Turbidity</td><td>correlations</td></tr>
</table>

			flow rates	turbidity
spearman's rho	flowrates	correlation coefficient	1.000	-.178
		sig. (2-tailed)	.	.134
		n	72	72
	turbidity	correlation coefficient	-.178	1.000
		sig. (2-tailed)	.134	.
		n	72	72

Carbonate hardness

correlations

			flowrates	carbonate
spearman's rho	flowrates	correlation coefficient	1.000	$-.424^{**}$
		sig. (2-tailed)	.	.000
		n	72	72
	carbonate	correlation coefficient	$-.424^{**}$	1.000
		sig. (2-tailed)	.000	.
		n	72	72

Nitrate

correlations

			nitrate	flowrates
spearman's rho	nitrate	correlation coefficient	1.000	$-.280^{*}$
		sig. (2-tailed)	.	.017
		n	72	72
	flowrates	correlation coefficient	$-.280^{*}$	1.000
		sig. (2-tailed)	.017	.
		n	72	72

Phosphate

correlations

			flowrates	phosphate
spearman's rho	flowrates	correlation coefficient	1.000	.026
		sig. (2-tailed)	.	.831
		n	72	72
	phosphate	correlation coefficient	.026	1.000
		sig. (2-tailed)	.831	.
		n	72	72

Iron

correlations

			flowrates	iron
spearman's rho	flowrates	correlation coefficient	1.000	.086
		sig. (2-tailed)	.	.472
		n	72	72
	iron	correlation coefficient	.086	1.000

		sig. (2-tailed)	.472	.
		n	72	72

Zinc

correlations

			flowrates	zinc
spearman's rho	flowrates	correlation coefficient	1.000	-.092
		sig. (2-tailed)	.	.440
		n	72	72
	zinc	correlation coefficient	-.092	1.000
		sig. (2-tailed)	.440	.
		n	72	72

Copper

correlations

			flowrates	copper
spearman's rho	flowrates	correlation coefficient	1.000	-.039
		sig. (2-tailed)	.	.746
		n	72	72
	copper	correlation coefficient	-.039	1.000
		sig. (2-tailed)	.746	.
		n	72	72

Total coliforms

correlations

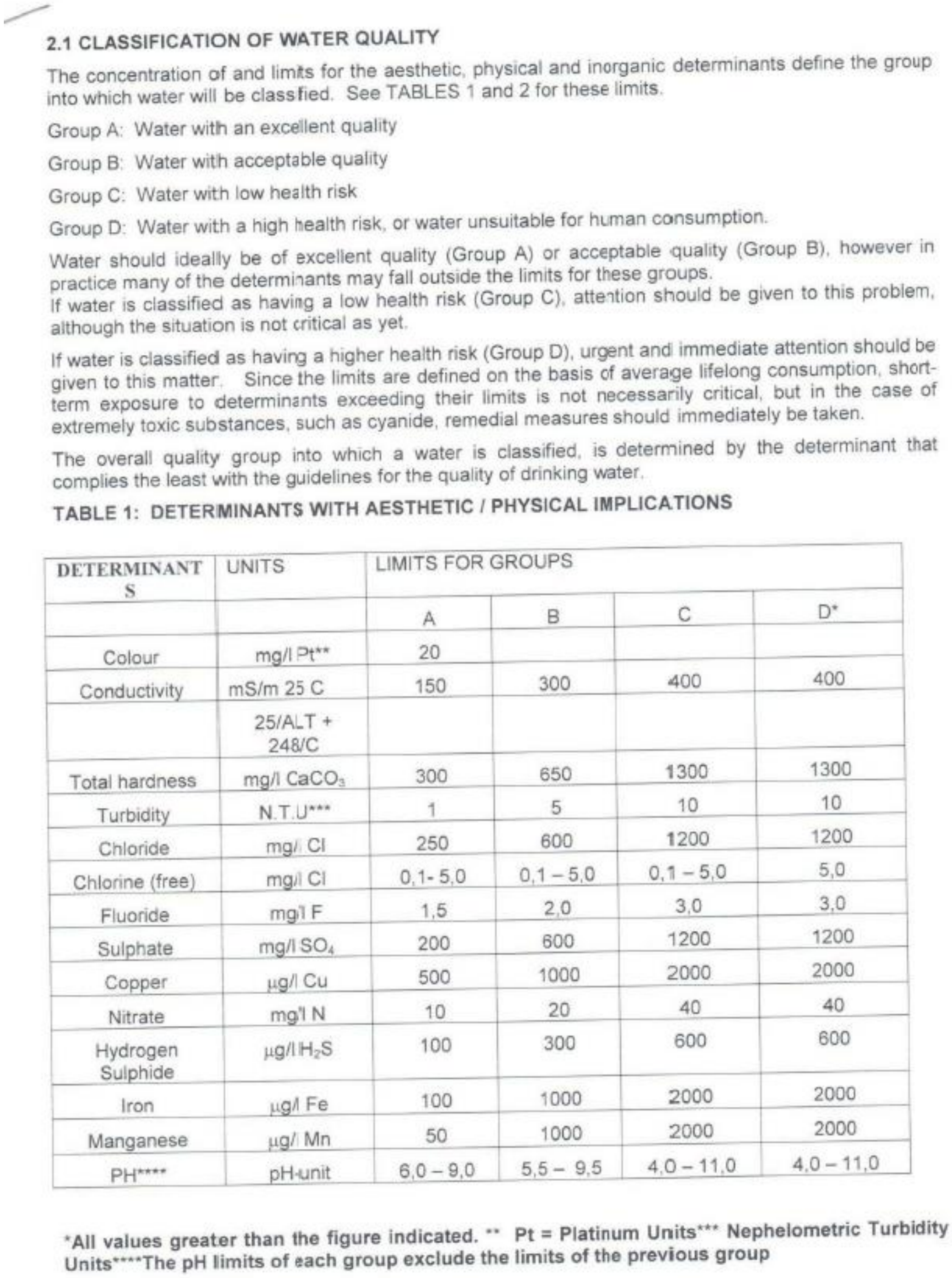
			flowrates	coliforms
spearman's rho	flowrates	correlation coefficient	1.000	-.062
		sig. (2-tailed)	.	.655
		n	72	54
	coliforms	correlation coefficient	-.062	1.000
		sig. (2-tailed)	.655	.
		n	54	54

E.coli

correlations

			flowrates	e.coli
spearman's rho	flowrates	correlation coefficient	1.000	-.078
		sig. (2-tailed)	.	.577
		n	72	54
	e.coli	correlation coefficient	-.078	1.000
		sig. (2-tailed)	.577	.
		n	54	54

APPENDIX 3.



2.1 CLASSIFICATION OF WATER QUALITY

The concentration of and limits for the aesthetic, physical and inorganic determinants define the group into which water will be classified. See TABLES 1 and 2 for these limits.

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.

Water should ideally be of excellent quality (Group A) or acceptable quality (Group B), however in practice many of the determinants may fall outside the limits for these groups.
If water is classified as having a low health risk (Group C), attention should be given to this problem, although the situation is not critical as yet.

If water is classified as having a higher health risk (Group D), urgent and immediate attention should be given to this matter. Since the limits are defined on the basis of average lifelong consumption, short-term exposure to determinants exceeding their limits is not necessarily critical, but in the case of extremely toxic substances, such as cyanide, remedial measures should immediately be taken.

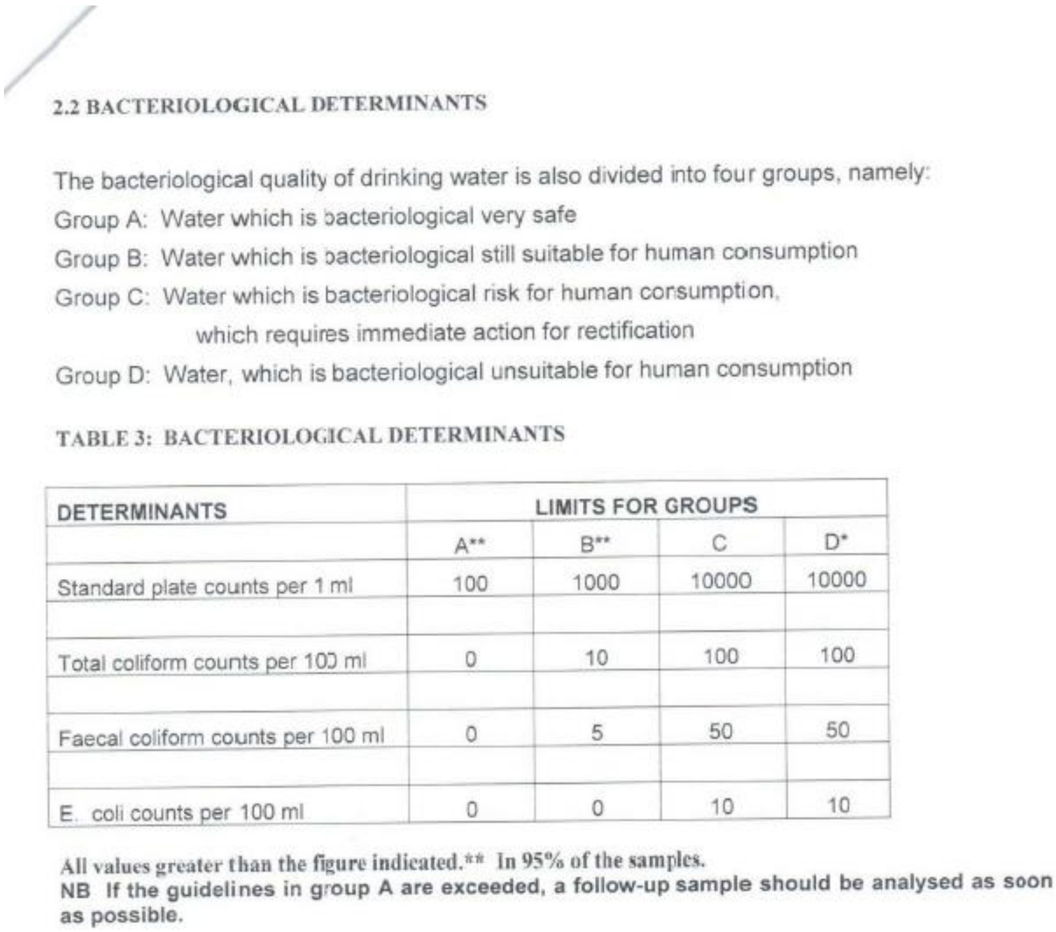
The overall quality group into which a water is classified, is determined by the determinant that complies the least with the guidelines for the quality of drinking water.

TABLE 1: DETERMINANTS WITH AESTHETIC / PHYSICAL IMPLICATIONS

DETERMINANTS	UNITS	LIMITS FOR GROUPS			
		A	B	C	D*
Colour	mg/l Pt**	20			
Conductivity	mS/m 25 C	150	300	400	400
	25/ALT + 248/C				
Total hardness	mg/l $CaCO_3$	300	650	1300	1300
Turbidity	N.T.U***	1	5	10	10
Chloride	mg/l Cl	250	600	1200	1200
Chlorine (free)	mg/l Cl	0,1- 5,0	0,1 – 5,0	0,1 – 5,0	5,0
Fluoride	mg/l F	1,5	2,0	3,0	3,0
Sulphate	mg/l SO_4	200	600	1200	1200
Copper	µg/l Cu	500	1000	2000	2000
Nitrate	mg/l N	10	20	40	40
Hydrogen Sulphide	µg/l H_2S	100	300	600	600
Iron	µg/l Fe	100	1000	2000	2000
Manganese	µg/l Mn	50	1000	2000	2000
PH****	pH-unit	6,0 – 9,0	5,5 – 9,5	4,0 – 11,0	4,0 – 11,0

All values greater than the figure indicated. ** Pt = Platinum Units Nephelometric Turbidity Units****The pH limits of each group exclude the limits of the previous group**

Figure 9.1. NamWater and Analytic Laboratory Services cc’s physical and chemical water classifications.



2.2 BACTERIOLOGICAL DETERMINANTS

The bacteriological quality of drinking water is also divided into four groups, namely:

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

TABLE 3: BACTERIOLOGICAL DETERMINANTS

DETERMINANTS	LIMITS FOR GROUPS			
	A**	B**	C	D*
Standard plate counts per 1 ml	100	1000	10000	10000
Total coliform counts per 100 ml	0	10	100	100
Faecal coliform counts per 100 ml	0	5	50	50
E. coli counts per 100 ml	0	0	10	10

All values greater than the figure indicated.** In 95% of the samples.
NB If the guidelines in group A are exceeded, a follow-up sample should be analysed as soon as possible.

Figure 9.2. NamWater and Analytic Laboratory Services cc’s biological water classifications.

APPENDIX 4.

Questionnaire for Hardap Region farmers (WATER)

Name …………………………………………………………………………..

Number…………………………………………………………………………

Farm name……………………………………………………………………...

1. How many households does the borehole supply water to?

…………………………………………………………………………………

.........................……………………………………………………………

2. What powers the borehole?

………………………………………………………………………………..

………………………………………………………………………………..

3. How many water tanks are currently on the farm?

……………………………………………………………………………….

……………………………………………………………………………….

4. How much water do you use a day?

……………………………………………………………………………….

……………………………………………………………………………….

5. What do you do with grey water?

……………………………………………………………………………….

……………………………………………………………………………….

6. What are your thoughts on the quality of the water?

……………………………………………………………………………….

………………………………………………………………………………

7. Do you still use the otji-toilet that was built in 2011? If not, why?

………………………………………………………………………………

………………………………………………………………………………

8. Have you or any of the people living on the farm experienced any water-related health concerns?

…………………………………………………………………………………………

…………………………………………………………………………………………

APPENDIX 5.

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM

ANNEX 5

TITLE OF THE RESEARCH PROJECT: Assessment of borehole water quality and efficiency of homemade water filter purification devices in Hardap Region, Southern Namibia.

REFERENCE NUMBER: 201202195

PRINCIPAL INVESTIGATOR ADDRESS CONTACT NUMBER: Tiffany Claasen, +264 81 720 8981, zana.claasen@gmail.com

You are being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff or doctor any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You will also be free to withdraw from the study at any point, even if initially you do agree to take part.

This study has been approved by the Research Ethics Committee at The University of Namibia and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and Namibian National Research Ethics Guidelines.

What is this research study all about?

In Hardap region, a quantitative study will encompass collecting, filtering and analyzing borehole water on five farms having deteriorated borehole infrastructure and an open dam system as this contributes to water contamination (Lewis & Claasen 2016).

Approximately 6.6% of Hardap Region has unsafe drinking water according to NamWater's guidelines (Namibia Statistics Agency, 2011); consumption of the unsafe water could cause various diseases. 5% of deaths in Namibia are due to diarrhea caused by consuming water with faecal pollution (CDC 2010). Minimal efforts have been done to improve the quality of unsafe water at point of consumption in Hardap Region, resulting in a lack of information regarding water quality improvements. The study's results will contribute to the formulation of guidelines on water resource use and add valuable knowledge as to which filters are best suited for Hardap Region's water quality challenges. It will also provide information on the efficiency of the homemade filters as an environmentally friendly and low cost water treatment for rural communities. Rural communities can also use this information to build their own homemade water filter devices to improve their livelihoods.

Why have you been invited to participate?

We have chosen your farm as you have an *open dam system.*

What will your responsibilities be?

All we ask of you is 20min for a short interview to ask questions on the water supply of your farm as well as 100L of borehole water.

We will collect the water on the day of the interview.

Will you benefit from taking part in this research?

No payment will be given to any participates, but knowledge on the most effective filter and the entire study will be distributed to the participants to use at their own comfort.

Are there in risks involved in your taking part in this research?

No immediate risks.

What will happen in the unlikely event of some form of injury is incurred as a direct result of your taking part in this research study?

As no physical or medical risks will be taken during the study, no compensation will be distributed.

Will you be paid to take part in this study and are there any costs involved?

No payment.

Is there anything else that you should know or do?

You will receive a copy of this information and consent form for your own records. You will get feedback on the provided study.

Declaration by participant

By signing below, I ………………………………..…………. agree to take part in a research study entitled: Assessment of borehole water quality and efficiency of homemade water filter purification devices in Hardap Region, Southern Namibia.

I declare that:

a) I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.

b) I have had a chance to ask questions and all my questions have been adequately answered.

c) I understand that taking part in this study is **voluntary** and I have not been pressurized to take part.

d) I may choose to leave the study at any time and will not be penalized or prejudiced in any way.

e) I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (*place*) ....…..…….. on (*date*) …………...………………

……….......................................	....
Signature of participant	Signature of witness

11. Declaration by investigator

I *TIFFANY CLAAASEN* declare that:

- I explained the information in this document to …………………..…………………..

- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above.
- I did/did not use an interpreter. (*If an interpreter is used then the interpreter must sign the declaration below*.

Signed at (*place*) ....…........…………….. on (*date*)
…………....……….. 2019.

....

Signature of investigator   Signature of witness

12. Declaration by interpreter

I *(name)* declare that:

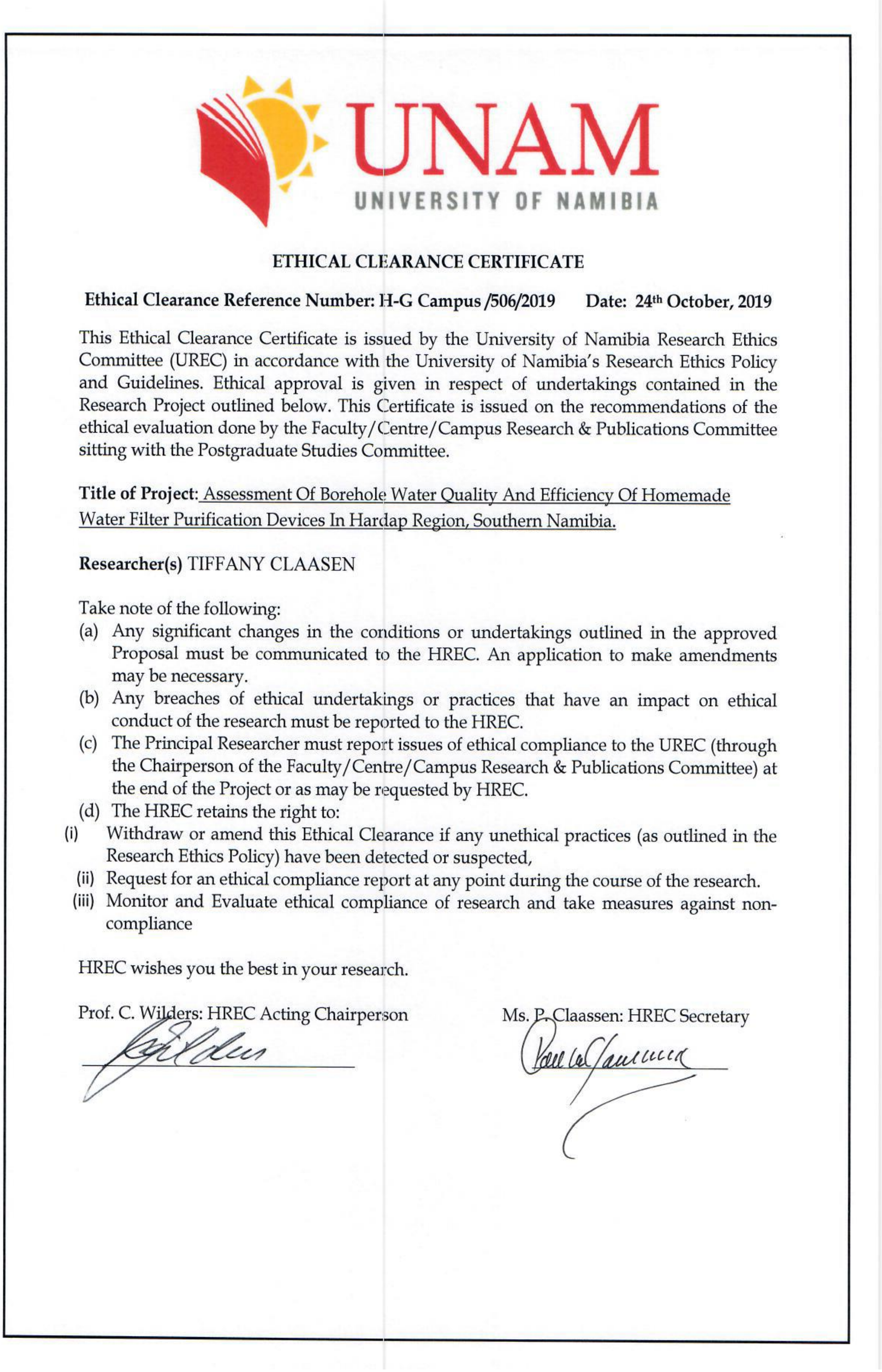
a) I assisted the investigator (*name*) ………………………………………. to

explain the information in this document to (*name of participant*)

……………..…………………………….. using the language medium of

(Oshiwambo, Oshiherero, Afrikaans, etc.)

APPENDIX 6.



UNAM
UNIVERSITY OF NAMIBIA

ETHICAL CLEARANCE CERTIFICATE

Ethical Clearance Reference Number: H-G Campus /506/2019 **Date: 24th October, 2019**

This Ethical Clearance Certificate is issued by the University of Namibia Research Ethics Committee (UREC) in accordance with the University of Namibia's Research Ethics Policy and Guidelines. Ethical approval is given in respect of undertakings contained in the Research Project outlined below. This Certificate is issued on the recommendations of the ethical evaluation done by the Faculty/Centre/Campus Research & Publications Committee sitting with the Postgraduate Studies Committee.

Title of Project: Assessment Of Borehole Water Quality And Efficiency Of Homemade Water Filter Purification Devices In Hardap Region, Southern Namibia.

Researcher(s) TIFFANY CLAASEN

Take note of the following:

(a) Any significant changes in the conditions or undertakings outlined in the approved Proposal must be communicated to the HREC. An application to make amendments may be necessary.

(b) Any breaches of ethical undertakings or practices that have an impact on ethical conduct of the research must be reported to the HREC.

(c) The Principal Researcher must report issues of ethical compliance to the UREC (through the Chairperson of the Faculty/Centre/Campus Research & Publications Committee) at the end of the Project or as may be requested by HREC.

(d) The HREC retains the right to:

  (i) Withdraw or amend this Ethical Clearance if any unethical practices (as outlined in the Research Ethics Policy) have been detected or suspected,

  (ii) Request for an ethical compliance report at any point during the course of the research.

  (iii) Monitor and Evaluate ethical compliance of research and take measures against non-compliance

HREC wishes you the best in your research.

Prof. C. Wilders: HREC Acting Chairperson

Ms. P. Claassen: HREC Secretary