Investigation of recycling perspectives of grey water for resource recovery in Witbank, South Africa

By

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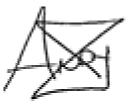

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Abstract

South Africa is a water scarce country. The demand for water is exceeding the supply significantly in some of the cities of the country. Simultaneously, a significant amount of grey water is generated by the households in the cities. Consequently, an argument has emerged that if grey water is treated and re-used for domestic use purposes, then it can contribute to the alleviation of the challenges to meet the water demand. Besides, grey water also constitutes significant amount of resources such as Nitrogen, Phosphorous and Potassium. Therefore, a study was done by considering the city of Witbank of the Mpumalanga Province in South Africa in order to examine the quality (impurities and nutrient content) of grey water generated in the study area, explore the appropriate treatment processes to treat the grey water to and to quantify the availability of Nitrogen, Potassium and Phosphorus so that resources such as water and chemical resources (Nitrogen, Potassium and Phosphorus) can be recovered from grey water. The study was motivated by the need to reduce the high demand for scarce fresh water and the amounts of generated waste water, and a resource recovery through recycling process can ease the pressure on the environment.

Grey water from bathrooms, showers, kitchens, laundry and sinks were collected from domestic water users of Witbank Mpumalanga Province, based on the location of the area such as central areas, upscale development and township of the city Witbank. Grey water samples were collected across the four seasons of the year and analysed in the laboratory for physical, chemical, operational, microbiological and resource content before and after treatment processes using various treatment combinations such as aerobic screening (AS), Multimedia Filtration (MMF), Ultraviolet radiation (UV) and Chlorination (CL). After treating grey water with a combination of MMF, AS and UV, the physical, chemical, operational and microbiological characteristics of grey water are compared with the standards recommended by the Department of Water Affairs and National Standards Specifications of South Africa. Also, a household survey targeting areas of Witbank as water users was carried out to collect household data relating to socio-economic

characteristics and water demand, water supply scenarios. The data collected was statistically analysed.

The results of the survey indicated that upscale development areas, had the highest income and household water usage followed by central areas, then townships and lastly the city. There was a significant ($p < 0.05$), correlation between income and water consumption. There was also a significant, positive ($p < 0.05$) correlation between income and grey water production. Household surveys indicated a significant, positive ($p < 0.05$) correlation between income, water consumption and grey water production. The results also confirmed that income, water consumption and grey water production across upscale development, city, the townships and central areas in Witbank were significantly ($p < 0.05$) different.

Regression analysis of income as an independent variable and water demand as a dependent variable indicated a linear and significant causal correlation between income and household water demand exists.

Results of the experimental study indicated that the physical, chemical, operational alert and microbiological characteristics of grey water improved significantly to fall within the standard stipulated by the Department of Water Affairs after subjecting untreated grey water to individual and a combination of aerobic screening (AS), Multimedia Filtration (MMF), Ultraviolet radiation (UV) and Chlorination (CL) treatment processes. The grey water also contains significant amount of Nitrogen, Potassium and Phosphorus. Therefore, if recycling of grey water is conducted appropriately then quality water for domestic use can be recovered and re-used. Also, there is a potential for recovery of significant amount of the chemical resources such as Nitrogen, Potassium and Phosphorus.

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CHAPTER 1: INTRODUCTION AND BACKGROUND

1.1 Introduction

Water crises are emerging worldwide at all levels. These crises occur nationally and even across entire regions. According to the World Economic Forum (2014), water scarcity now ranks as the third most concerning global risk, although the nature of water crises differs from one country to another as well as within individual countries.

South Africa is a water-scarce country. Of the 223 river ecosystem types in South Africa, 60% are threatened and 25% of those are critically endangered. South Africa is characterized by low and variable annual rainfall along with high natural evaporation levels, making it the 30th driest country in the world (DWA, 2013). Average annual rainfall in South Africa is only 495 mm (World Bank, 2013) and evaporation losses are often three times more than rainfall. Furthermore, the meagre rainfall is unevenly distributed, with some regions receiving less than 100 mm of rain in a year on average (FAO, 2013).

Low and unpredictable supply, coupled with high (and growing) demand and poor use of existing water resources, make South Africa a water-constrained country. As a result of this, demand for water in South Africa currently almost outstrip supply and the gap or deficit continues to grow and is estimated to reach over 3.5 km^3 by 2030(DWA, 2013). This has serious consequences on the environmental resilience of aquatic ecosystems and the reliability of water supply for human consumption. Furthermore, this over-exploitation increases the vulnerability of the water system to shocks such as drought and will be aggravated by the impact of climate change.

The critical importance of water to sustainable development is clearly recognized in the Millennium Development Goals. Freshwater is a fundamental requirement for human survival and socio-economic development and must therefore be wisely managed. Furthermore, it is also argued that reducing the needs for fresh water can be achieved by reusing waste water (Jaramillo and Restrepo, 2017). Grey water (water discharges from laundries, showers, baths, sinks and kitchens) has been perceived to have great potential for re-use in irrigation and toilet flushing. This potential for reuse is mostly due to its availability (around 70% of domestic waste water) and low concentration of pollutants compared with combined household waste water (Hills, Birks, Diaper & Jeffrey, 2008).

If grey water is recycled appropriately, it becomes a significant source of water that could potentially cover for the lack of fresh water. However, the most common use of recycled wastewater is for agricultural irrigation (Laine, 2007). Other common uses of recycled water include industrial, recreational, and environmental re-use. More specific, recycled grey water can be used for toilet flushing, gardening and irrigation, washing machines and other applications such as car washing, and firefighting.

It is conceivable that household recycled grey water is a valuable resource that should be used as part of a wider water demand management strategy. Recycling of grey water and the re-use thereof for domestic and agriculture purposes can reduce pressure on the demand for water. South Africa being a water scarce country merits an investigation into grey water recycling. This study has therefore been undertaken to investigate the recycling of grey water and quantify the availability of various resources in the South African city of Witbank.

1.2 Background of the study area

The city Witbank, also known as eMalahleni is situated on the Highveld of Mpumalanga, South Africa. It is about 112 kilometres south east of Pretoria. Witbank is one of the fastest growing urban areas in South Africa that is largely driven by coal mining activities. The population of Witbank as at 2011, stood at 311 657 (STATSA, 2013).

Witbank is located along the railway line linking Pretoria to Maputo and serves as a transport gateway to these Mozambican ports. Two national highways, the N4 from Pretoria and the N12 from Johannesburg converge at Witbank and then continue to Komatipoort, on the border of Mozambique. These routes form the Maputo Corridor, a strategically important alternative to the South African ports of Richards Bay and Durban on the Indian Ocean shores of the country.

The continued growth of Witbank commercial areas and suburbs has presented challenges to the municipality. Potable water supplies and water treatment are particularly one of the critical problem areas for this municipality. The city suffers from recurrent water shortage and the quality of the water is also found to be poor with a low pH of less than 4.3, heavy metal content from steel manufacturing plants, and the presence of vanadium, chrome and aluminium in its toxic configuration (Munnik, Hochmann and Law, 2010). Furthermore, since Witbank is a mining town some tests being carried out have shown high acidity levels and heavy metal content, which include copper and iron (Gunther and Mey, 2006). The water purification plant of the city is highly unreliable as it regularly breaks down due to lack of maintenance (DWA, 2013). These break downs are compounding portable water shortages within the city. On other hand, it is observed that the city generates 2 558.8 cubic meters of grey water per day (Van Rooyen, Van Niekerk and Versfeld, 2011).

1.3 Importance of the study

It is possible to reduce the amounts of fresh water consumption as well as re use wastewater through grey water recycling (Hamilton, Stagnitti, Kumarage, Premier, 2012). Hamilton et al. (2012) further state that grey water recycling not only saves fresh water but is also efficient, cost effective and can significantly reduce bills associated with water usage Hamilton et al. (2012). If grey water is regarded as an additional water source, an increased in the supply of irrigation water can be ensured which will in turn lead to an increase in agricultural productivity. In addition to the benefits being highlighted above, grey water is rich in phosphorous, potassium, and nitrogen, making it a good nutrient or fertilizer source for irrigation (Hills, Birks, Diaper and Jeffrey, 2008).

Grey water systems bring significant savings in fresh drinking water in addition to reducing the amounts of generated wastewaters, thus easing the pressure on the environment. As grey water recycling is not dependent on season or variability of rainfall, it is a continuous and a reliable water resource. Therefore, recycling of grey water can potentially reduce water demand in the cities of South Africa.

1.4 Problem Statement

The water quality around Witbank city tested to be acidic with higher than expected metal content, including high levels of copper and the presence of iron (Gunther and Mey, 2006). Consequently, the eMalahleni Local Municipality, BHP Billiton and Anglo Coal established of a major mine water reclamation plant. Acidic, saline and underground water from four nearby coal mines is treated and purified to drinking water standards and supplied to the Municipality.

The treatment process in Witbank is designed to produce water that meets the South African National Standard for Drinking Water Quality (SANS 0241 Class 0 potable water). It uses the High Recovery Precipitating Reverse Osmosis (HiPRO) process that generates a water product of low salinity by the membrane process. The chief characteristic of this design is that it makes use of Reverse Osmosis to concentrate the water and produce supersaturated brine from which the salts can be released in a simple precipitation process. However, this option of treating acid mine water is capital intensive and way beyond the means of the municipality.

Since Witbank is one of the fastest growing urban areas in South Africa, the city is faced with the considerable difficulty of meeting the increasing demand for clean drinking water. The Witbank area has been experiencing an increase in water demand of 3.5% per annum on average (Hodgson, 2008). The Emalahleni Local Municipality, the statutory local water service authority for Witbank, already exceeds its licensed abstraction of 90 ML/d from Witbank Dam by 11 ML/d. By 2030, the municipality's water demand is forecast to be 50% higher at 180 Ml/day (Gunther et al., 2006). Carden, Armitage, Winter, Sichone, and Rivert (2006), reported that, it was not possible to accurately measure out of the total amount of water consumed the volumes of grey water generated at household and national levels in South Africa. However, a large proportion (estimated at 75%) of the water used during any day is discarded as grey water.

The recycling of grey water and re-use thereof domestic purposes will thus reduce the pressure on water demand. Therefore, a study regarding recycling of grey water will be conducted in a South African city with Witbank as a case study.

1.5 Objectives of the study

The specific objectives of this study are to:

- Estimate the quantity of grey water in the Witbank city
- Examine the quality (impurities and nutrient content) of grey water generated in the study area and quantify the availability of different resources such as Nitrogen, Potassium and Phosphorus which can be recovered from grey water
- Process grey water under various simulated scenarios of individual and a combination of different treatment processes
- Make a comparative analysis between treated grey water of acceptable standard and untreated grey water
- Proffer plausible strategic guidelines for possible re-use of processed grey water as domestic service water as well as for resource recovery from grey water.

1.6 Contributions of the study

The main contributions of the study include the following;

- Design of appropriate methods of treatment
- Estimation of nutrient recovery
- Possible use of grey water

1.7 Chapter overview

This study comprises of five chapters where the first chapter provides an introduction and background information. Issues covered in the first chapter include importance of the study, the problem statement, objectives and contribution of the study.

Chapter 2 present a review of literature associated with research. This includes analysis grey water recycling to minimize stress on water resources.

Chapter 3 provides a detailed description of the study area. Issues that are covered include location, the population profile, water sources in and around Witbank, water demand and supply, water challenges, water quality, main economic sectors of Witbank, social and environmental issues.

Chapter 4 discusses the research method which encompasses the research design, sampling method, data collection instruments, laboratory experiments, data analysis and ethical considerations.

Chapter 5 provides detailed results, discussions and findings of this study.

Chapter 6 provides a conclusion and recommendations. Limitations of the study and scope for further studies are also covered in this chapter.

1.8 Conclusion

Since South Africa is faced with a potable water supply problem due to low and unpredictable supply, coupled with a high (and growing) demand and poor use of existing water resources, it is critical to find sustainable solutions as a matter of urgency (DWA, 2013). Grey water recycling has great potential for re-use due to its availability.

Recycled grey water can be a significant source of water that could potentially cover for the lack of fresh water (Laine, 2007). More specific, recycled grey water can be used for toilet flushing, gardening and irrigation, washing machines and other applications such as car washing, and firefighting. Therefore, recycled grey water can be used as a valuable resource to meet the ever increasing water demand.

Chapter 2: Literature Review

2.1 Introduction

South Africa is a water scarce country and the sustainable provision of water to its citizens is one of the most significant challenges facing the country (Allen,Bryan and Woelfle-Erskine, 2013). A recurrent argument has emerged that if the water crisis is to be averted, existing systems will need to be managed effectively (Schneider, 2009). Furthermore, Schneider (2009) argued that one of the ways of reducing the needs for fresh water is through the re-use of grey water. If grey water is recycled appropriately, it becomes a significant source of water that could cover for the lack of fresh water.

This chapter provides literature on grey water, methods and technologies used for grey water, research works on grey water and resource recovery, as well as the treatment process and challenges associated with it.

2.2 Definition of grey water and wastewater

Household wastewater is defined by Palmquist and Hanaeus (2010) as water that has been adversely compromised in quality as a result of human activities such as bathing, dishwashing, laundry and toilet flushing. The main contaminants in wastewater include soaps, detergents, urine, faecal material and oils among other things. In agreement to this definition, Schneider (2009) defines household wastewater as a combination of grey water and black water (i.e. water from toilets containing faecal matter and urine that can hardly be recycled).

On the other hand, grey water is defined by Eriksson, Auffarth, Henze & Ledin (2002) being discharged from the shower, hand basin, bath, laundry and kitchen. Eriksson et al., (2002) further state that grey water accounts for about 75% of wastewater produced in the household. In their definition of grey water, Allen et al., (2013) state that grey water includes wastewater from washing, bathing, wash basins and laundry but not water from toilets or any wash water containing faecal material. Contrary to Eriksson et al, (2002), Allen et al., (2013) classify kitchen sink water as dark grey water. However, Schneider's (2009) definition of grey water as wastewater generated from the bathroom, laundry and kitchen, is totally in agreement with that of Eriksson et al., (2002). Schneider (2009) defines grey water as wastewater generated from bathroom, laundry and kitchen. He further states that most grey water is easier to treat and recycle because of lower levels of contaminants. Thus the used water generated from bathrooms, showers, laundry washing, kitchen and hand basins can safely be termed grey water.

2.3 Implications of grey water

Debates on the reuse of grey water in order to ease the challenges of higher water demand have emerged in recent years. It is advocated that grey water can be used as domestic service water or water for irrigation purposes. According to Marshall (1996) and Erguder et al. (2009) does the presence of contaminant elements such as soap, shampoo, toothpaste, shaving cream, food scraps, organic matters, and nutrients (e.g. nitrogen, potassium etc.) in grey water not necessarily harm the garden soils and plants if this water is used for irrigation purposes. However, care need to be taken to remove pollutants with high salt and phosphorus concentrations (such as powdered laundry detergents), which can stunt plants with low phosphorus tolerance before using the grey water for irrigation purposes (Marshall, 1996; Erguder *et al.,* 2009). In contrast, there are a number of problems related to the re-use of untreated grey water as domestic service water such as toilet flushing. One of the major risks is the spreading of diseases due to the exposure to microorganisms in the water. Another problem is the risk of sulphide production, which occurs when oxygen is depleted and generates a bad odour. Growth of microorganisms within grey water that remains untreated over a long period of time is another concern (Eriksson *et al.,* 2002; Funazimu, 2009). Besides, the presence of suspended solids and turbidity could cause clogging of not only soil pores but also plumbing and water distribution installations (Eriksson *et al.,* 2002). Therefore, before grey water can safely be re-used as domestic service water or for irrigation purposes, apposite treatment thereof is essential to attain an appropriate physical, chemical and biological water quality.

However, before installing any treatment system, relevant treatment processes and the factors influencing the treatment process should be considered and evaluated to select and install an appropriate treatment system. The most important factors that need to be considered and evaluated include costs, physical and geographical environment, local availability of manpower and material, social and socio-economic circumstances, legal framework, characteristics and quantities of grey water and availability of the various wastewater treatment technology (Morel, 2002; Li *et al.,* 2009; Misra *et al.,* 2010).

2.4 General characteristics of grey water

Grey water contains various resources depending on the source. Barker-Reid et al., (2010) observed that grey water contains sodium, chlorides, and other nutrients such as nitrogen (N), ammonia (NH3) and phosphates. Travis et al., (2008), observed that the large quantities of sodium (Na) and phosphates (PO4) found in grey water emanate from washing machine powders. They note that washing detergents are the primary source of phosphates in grey water in countries that have not yet banned phosphorus-containing detergents. Similarly, according to Barker-Reid et al., (2010) and Carden, Armitage, Sichone & Winter (2007) grey water contains chlorides, ammonia, phosphates and sodium in considerable amounts. However, Carden et al., (2007) further observed that grey water also contains significant amounts of boron and cadmium. Correspondingly, Bolivian researchers Al-Zu'bi & Al-Mohamadi (2008) discovered a significant presence of heavy metal concentrations such as cadmium and nickel in grey water. However, the grey water that was used in Al-Zu'bi & Al-Mohamadi's

(2008) investigation was not only sourced from households but included industrial wastewater. Palmquist and Hanaeus (2010), who investigated the availability of resources in grey water from ordinary Swedish households, found mainly calcium, iron, potassium, sodium, magnesium, cadmium, cobalt, copper, lead, tin and zinc in the grey water. Eriksson, Srigirisetty and Eilersen (2012) argue that metals in grey water have not been studied in great detail. However, they insist that the concentrations found in the influent and effluent grey-waters in Denmark agree with results obtained by (Palmquist and Hanaeus, 2010) in Sweden. The only difference is that Eriksson, Srigirisetty and Eilersen (2012) found high levels of cadmium (9.0 μ g/ℓ) in grey water. Eriksson et al. (2012) further observed that resources such as ammonium, nitrogen, nitrogen, phosphorus, nitrates and nitrites are found in grey water. Their availability is dependent of grey water sources Eriksson *et al.,* (2012). They further stated that since grey water is wastewater from washing, bathing, wash basins and laundry, its main contaminants include organic material, soaps, detergents and various oils.

Based on the above arguments, it can be concluded that grey water contains contaminants such as organic material, soaps, detergents and oils. However, it also contains nutrients such as sodium, chlorides, nitrogen (N), ammonia (NH3) and phosphates among other nutrients. The quantities of the contaminants and nutrients in grey water are dependent on the source of the grey water.

2.5 Challenges of grey water

Grey water usage presents a number of challenges, some of which include the way it is stored, its quality and general public health concerns. A detailed discussion of these challenges follows in the sub-sections below.

2.5.1 Grey water storage challenges

Carden, Armitage, Sichone & Winter (2007), are of the opinion that grey water storage is difficult and presents an opportunity for pathogen growth. Along an increase in the number of pathogenic micro-organisms depletion of oxygen occurs which can result in a very bad odour. Many authors agree that it is better to avoid grey water storage, but disinfection of the grey water could offer a solution to the problem (Carden et al., 2007).

Ngaga, Karuiki & Kotut (2012) were of the view that there are a number of problems related to the use of untreated grey water. They argue that the risk of spreading of diseases due to the exposure to microorganisms in the grey water is a crucial point if grey water is to be re-used for toilet flushing or irrigation. Both inhaling (aerosols) and hand to mouth contact can be dangerous. The possible growth of micro-organisms and some chemicals within an untreated grey water system is another source of concern (Eriksson et al., 2002). Grey water intended for re-use must also be of satisfactory physical quality. Palmquist and Hanaeus (2010) are of the view that suspended solids in grey water can cause clogging of the distribution system. They also argue that there is always a risk of sulphide production, which is produced when oxygen is depleted and results in a bad odour.

According to Misra, Patel & Baxi (2009), tanks containing grey water provide an ideal breeding ground for pathogenic microorganisms and mosquitoes. This is a source of a pungent smell that poses a health hazard. They recommend that grey water tanks need to be vented and child-proof and should comply with local health by-laws. Such tanks should be accessible for cleaning. According to Murphy (2011), storage of grey water requires the addition of a disinfectant to avoid the biological degradation of fats, soaps and hairs. He further states that since the characteristics of grey water depend on the products used in bathrooms, laundry and eventually the kitchen, there is no simple solution in selecting appropriate disinfectants.

Therefore, storage of grey water presents a number of challenges. It has a pungent smell due to sulphide production, provides an ideal breeding ground for pathogenic microorganisms and mosquitoes and hand-to-mouth contact can be dangerous. It is therefore essential to avoid storage of grey water if possible. However, grey water can be disinfected to reduce production of pathogens and odour. Grey water tanks need to be vented and cleaned regularly to maintain high hygiene standards.

2.5.2 Grey water quality concerns

According to Qishlaqi, Moore & Forghani (2008), variation in the quality of grey water is one of the challenges being faced in grey water usage. Qishlaqi et al., (2008) argue that grey water often contains excessive salts, total suspended solids (TSS), biochemical oxygen demand (BOD) and nutrients such as nitrogen, ammonia and phosphates all of which can be harmful to plant matter.

When the quality of grey water content exceeds normal acceptable levels, treatment is recommended. However, Al- Hamaiedeh (2010) argues that the treatment process is naturally difficult and comes at a considerable cost. Again if grey water is used without prior treatment, it leads to problems such as elevated levels of soil salinity, lower water infiltration rate, specific ion toxicity (sodium, chloride and boron), and changes in soil properties, elevated pH levels, and the accumulation of heavy metals (Qishlaqi et al., 2008) which can negatively affect plant growth (Gross et al., 2005; Carden et al., 2007).

In summary, the quality of grey water presents some concerns in terms of its high levels of salts, total suspended solids, biochemical oxygen demand and nutrients that are harmful to plant life. If grey water is used without prior treatment, it can lead to high soil salinity, water infiltration problems, high toxicity, high pH levels and accumulation of heavy metals.

2.5.3 Public health concerns of grey water use

According to (Sheikh, 2010) grey water may at times contain sewage contaminants albeit in lower concentrations compared to black water, the sewage concentration levels in grey water may well be above international drinking, bathing, and irrigation water standards. Maimon, Tal, Friedler & Gross (2010) emphasise that grey water can contain pathogens not only derived from faecal contamination and food handling, but also opportunistic pathogens such as those found on the skin, which can pose a public health hazard.

It has also been established that grey water contains substantial amounts of cadmium. According to Jarup (2010), human exposure to even low levels of between 2 to 3 μg of cadmium /g may result in kidney damage, and affect bones that may lead to fractures. Grey water is contaminated underground with nitrogen, phosphate and heavy metals which poses a hazard to human, plant and sea life (Al-Zu'bi & Al-Mohamadi (2008).

It can be summarized that grey water may contain pathogens that can pose a public health hazard. Low levels of cadmium found in grey water can also cause kidney damage, and affect bones that may lead to fractures. Furthermore, pose nitrogen, phosphate and heavy metals in grey water hazards to both human and plant life.

2.5.4 Effect of grey water on plant growth and production

Due to the fact that grey water contains toxic substances such as chlorides, boron and cadmium in excessive amounts, plant growth is negatively affects (Rusan et al.,2013). It should be noted that although these plant nutrients are essential for plant growth, they are only required in relatively small concentrations. Furthermore, Omami (2011) established that salinity affects plant growth in a variety of ways which include reduced infiltration, a deterioration of the physical structure of the soil, which diminishes permeability and soil aeration. Salinity also causes an increase in the concentration of certain ions which have an inhibitory effect on plant metabolism. The general response of plants to soil salinity is a reduction in plant growth which includes germination (Agarwal & Pandey, 2011).

Bauder et al., (2011) suggests that soils with a high concentration of salts often suffer from severe leaf damage and general crop failure. Research on the external quality of crops being irrigated with grey water is limited. However, Zavadil (2009) discovered that grey water does not improve the crop quality of sugar beet (sugar content) and the starch percentage of early potatoes.

In summary, high levels of toxic substances in grey water such as chlorides, boron and cadmium negatively affects plant growth and it has once more been established that, soil salinity inhibits plant growth and germination.

2.6 Resources available in grey water

Subjected to the sources of the grey water, it contains various resources. Barker-Reid et al., (2010) observed that grey water contains sodium, chlorides, and other nutrients such as nitrogen (N), ammonia ($NH3$) and phosphates. In addition, Travis et al., (2008), observed that the large quantities of sodium (Na) and phosphates ($PO4$) that are found in grey water emanate from washing machine powders. They noted that washing detergents are the primary source of phosphates in the grey water of countries that have not yet banned phosphorus-containing detergents.

A similar study to Barker-Reid et al., (2010) by- Carden, Armitage, Sichone & Winter (2007) established that grey water contains chlorides, ammonia, phosphates and sodium in considerable amounts. Carden et al., (2007) furthermore observed that grey water also contains significant amounts of boron and cadmium. Correspondingly, Bolivian researchers Al-Zu'bi & Al-Mohamadi (2008) discovered heavy presence of high levels concentrations such as cadmium and nickel in grey water. However, the grey water being used in the investigation of Al-Zu'bi & Al-Mohamadi's (2008) was not solely sourced from households, also but included industrial wastewater.

The investigation of Palmquist and Hanaeus (2010) into the availability of resources in grey water from ordinary Swedish households, confirmed the presence of mainly calcium, iron, potassium, sodium, magnesium, cadmium, cobalt, copper, lead, tin and zinc. Although Eriksson, Srigirisetty and Eilersen (2012) argue that metals in grey water have not been studied in great detail, they admit that their investigation into concentrations in the influent and effluent grey-waters of Denmark correlate with the results obtained by (Palmquist and Hanaeus, 2010) in Sweden. The only difference being that Eriksson, Srigirisetty and Eilersen (2012) also found high levels of cadmium (9.0µg/ℓ) in grey water. Eriksson et al., (2012) further observed that contingent upon the sources of the grey water, non-metal resources such as ammonium, nitrogen, nitrogen, phosphorus, nitrates and nitrites are also found in grey water.

It can be summarised that subject to the source of the grey water, it contains on the one hand various resources - such as chlorides, ammonia, phosphates and sodium - in considerable amounts and on the other hand baron, cadmium and heavy metals. The large quantities of sodium and phosphates in grey water emanate from washing powders.

2.7 Methods and technologies used for Grey water treatment

There are a number of technologies varying both in complexity and performance – that are worldwide applied for grey water treatment. According to Elmitwalli, Shalabi, Wendland and Otteroshi (2007), grey water can be treated using low cost methods such as the manual bucketing of grey water from the of bathroom outlet, to primary treatment methods that coarsely screen oils, greases and solids from the grey water before irrigation to more expensive secondary treatment systems that treat and disinfect the grey water to a high standard before use for irrigation. Generally, grey water treatment systems are classified into primary and secondary treatment systems. Primary systems involve screening while secondary systems consist of filtration, ultraviolet disinfection and chlorination.

2.7.1 Primary treatment systems

Screening is the commonest primary treatment process that is used in recycling grey water. According to Misra et al., (2010), screening is the first process that is applied during recycling of grey water. This process basically involves removal of large proportion of suspended matter which can be grease, silt and soap froth. There is also an aerobic screening process that efficiently reduces insoluble material to a negligible residue. This residue is usually discharged to sewer and the remaining grey water flows into the second module for secondary treatment (Nagata and Funamizu, 2009).

2.7.2 Secondary treatment systems

After aerobic screening, grey water goes through multi-media filtration process (MMF) constituting various media which include fine sand, coarse sand, gravel, stone, anthracite coal and wood chips to a total depth of 75 centimetres. The inlet of a filtration process is provided at the top so that the filtered water is collected through outlet in the bottom. A vent is provided at the top to let out any odorous emissions, generated in the filter. Depending on the characteristics and quantity of the grey water, media in the water can be removed through periodical washing (Li, Wichmann & Otterpohl, 2009)

Media filtration can take the form of basic sand filters, multi-media filtration systems, or reed beds. The removal of microorganisms by media filtration relies on their deposition within the media bed by either adsorption to the media surface or through entrapment in pores between media granules (Nagata and Funamizu, 2009). Counteracting this deposition, however, is a process of microorganism dislodgement caused by movement of the applied water through the media bed. Nagata and Funamizu, 2009), further state that dislodged microorganisms are transported by the water and may be deposited further down the media bed or ejected with the filtered effluent. During the filtration process, water is passed through a filter medium in order to remove the particulate matter not previously removed by sedimentation. In filtration, the turbidity and colloidal matter of non-settleable protozoan cysts and helminth eggs are also removed (Nagata and Funamizu, 2009).

There are different types of filters. With the upflow-downflow filter raw grey water is put into the bottom of the first column of the filter and collected at the top of the second column. This water is again fed to the third column of the filter from the bottom and is collected at the top of the fourth column in that order (Roesner, 2010). He furthermore argues that although an optional upflow-downflow filter has about four columns, the number of columns required is determined by the quality and expected use of the grey water.

Slow sand filters are shallow layers of stone, medium gravel, and pea gravel beneath a deep layer of sand. According to Revitt, Eriksson, & Donner (2011), a slow sand filter will have a grey water load of 0.1 to 0.2m3/m2/hour. These gravity filters may be constructed in a 200 litre drum container. Basic features of such a filter include a perforated plate or some other device to distribute water evenly over the top; a concrete funnel in the bottom to help water drain to the perforated drain pipe; and a cover and vent to prevent odours. The bottom of the filter should be filled with stones that are too large to enter the drain pipe (Li et al., 2009).

According to Hourlier, Masse, Jaouen, Lakel, Gerente, Faur & Cloirec (2010), the horizontal flow filtration technique which uses coarse gravel or crushed stone as a filter media is also a sound alternative in handling turbid waters. The main advantage of the horizontal flow filter is that when the raw water flows through it, a combination of filtration and gravity settling takes place which invariably reduces the concentration of suspended solids (Hourlier et al., 2010). Because the effluent from the pre-filter is less turbid, it can easily be further treated with a slow sand filter.

According to Fischer, Wieltschnig, Kirschner & Velimirov (2010), membrane filtration involves the passing of water under pressure through a microfiltration (0.1 – 0.9 μm pore size) or ultrafiltration (0.01 – 0.09 μm pore size) membrane. Microorganism retention is achieved by size exclusion, when the membrane pore size is smaller than the microorganism size. A significant level of retention can also be achieved with pore sizes larger than the targeted microorganism due to adsorption to the membrane, which is controlled by hydrophobic and electrostatic interactions (Fischer et al., 2010).

Membrane filtration is often used in conjunction with an activated sludge process as part of a membrane bioreactor (MBR). The combined process has been shown to provide superior removal of biodegradable organics when treating grey water, compared to membrane filtration alone (Friedler et al., 2011). MBR systems are increasingly used for wastewater treatment in areas requiring high quality effluent and have been identified as well-suited to treatment and disinfection for water re-use (Zhang and Farahbakhsh, 2010).

Zhang and Farahbakhsh (2010) emphasise that due to the size exclusion, membrane filtration is typically most effective for the removal of larger pathogens, such as protozoa, followed by bacteria, and then viruses. Membrane filtration is generally more robust and less susceptible to microorganism breakthrough than media filtration, particularly when treating poorer quality effluents. However, bacteria have been shown to pass through membranes with nominal pore sizes smaller than the bacteria itself (Merz et al., 2010).

After filtration the next step in grey water treatment, is ultraviolet disinfection (UV). According to Elmitwalli, Shalabi, Wendland and Otteroshi (2007), this process involves ultraviolet lamps as a precautionary barrier against pathogens. Finally, chlorine (CL) residual is added to the recycled water to treat it and remove bad odours while in storage. Storage tanks can be made of different materials e.g. concrete, steel tanks, fiber glass, plastic or site built tanks (Tal, Sathasivan, Krishna, 2011).

Thus, various filtration methods can be used for the treatment of grey water. The multi-media filtration process (MMF), involves fine sand, coarse sand, gravel, stone, coal and wood chips to a total depth of about 75 centimetres for the physical treatment of grey water. Other treatment methods include the horizontal flow filtration technique which uses coarse gravel or crushed stone as a filter media. This method is a good alternative in handling turbid waters. Membrane filtration involves the passing of water through a microfiltration membrane. With this method microorganism retention is achieved when the membrane pore size is smaller than the microorganism size. In areas requiring high quality effluent membrane filtration is often used with an activated sludge process as part of a membrane bioreactor (MBR), for its superior removal of biodegradable organic matter. Strategies for grey water recycling

2.7.3 The collection system

There are different ways of collecting the grey water from households. Essentially, there must be a clear separation between the conventional wastewater disposal and the grey water collection system. Commonly, the flow of water from each household to the treatment facility is maintained by gravity (Finely, Barrington, & Lyew, 2008). To ensure clear separation, a one-way direction valve must be installed, to allow passage of excess grey water into the central sewage system. In newly designed systems it may occasionally raise issues of sewage flowing from the residential suburbs to the main treatment facilities, out of town. Other means of separation include accessories with an inverted screwing and frequently accompanied by clear labelling and identification. The grey water collection system can also be painted with a colour different from that of the other wastewater collection system (Leshem *et al.,* 2013).

Grey water treatment is related to the concept of source-separated effluent, which can facilitate treatment and re-use. Such separation is often considered an option for rural areas (Nelson and Murray, 2008). Larsen et al. (2009), however, state that this can be a sustainable alternative to end-of-pipe systems, inclusively in urban areas and industrialized countries.

Hernandez, Leal et al. (2010) discuss the concept of decentralized sanitation and re-use, which proposes the separation of domestic sewage into black water (toilet effluent) and grey water, in order to provide a more specific treatment for each type of effluent and allow the use of resources that would be discarded. Thus, grey water has an aggregate value and should not be considered waste. Friedler and GIlboa (2010) state that through the installation of grey water treatment units in households, commercial buildings, industries and other establishments, the treated effluent can be used in activities at the very place where it is produced. Muthukumaran et al. (2011) state that use of grey water for toilet flushing and landscape irrigation can reduce water consumption to at least 50%. It is extremely important to establish norms and regulations regarding grey water quality to minimize risks to users. The coherent definition of criteria is also necessary to avoid setting too high limits and the unnecessary requirement of very sophisticated treatment technologies, which make re-use a lot more difficult and even unfeasible. Worldwide, there are only a few norms and regulations specifically for grey water re-use; therefore, those defined for effluent re-use are usually applied.

There are different ways of collecting household grey water. One collection method separates domestic sewage into black water and grey water, in order to allow treatment of each type of effluent. Other methods include accessories with an inverted screwing that have clear labelling and identification. For distinction, the grey water collection system is usually painted with a colour different to that of the wastewater collection system. There are other sophisticated treatment technologies that are non-cost effective and make re-use more difficult and unattainable.

2.7.4 The treatment system

The treatment system consists commonly of a settling element, a screening/filtering component and a biological process that can include membrane technology element or constructed wetlands components. All these are aimed at treating the grey water, allowing their use for on-yard irrigation and/ or toilet flushing. Frequently, an element of disinfection (a small UV lamp and/or chlorination) is included in the treatment processes (Leshem *et al.,* 2013).

According to Elmitwalli, Shalabi, Wendland and Otteroshi, (2007), grey water treatment involves many strategies such as aeration, multi-media filtration, ultraviolet disinfection and chlorination. Aerobic screening (AS) is a unique odour free process that efficiently reduces insoluble material to a negligible residue. This residue is usually discharged to sewer and the remaining grey water flows into the second module. After aerobic screening, grey water goes through a multimedia filtration process (MMF) constituting various media that include fine sand, coarse sand, gravel, stone, anthracite coal and wood chips to a total depth of 75 centimetres. The inlet of a filtration process is provided at the top so that the filtered water is collected through outlet in the bottom. A vent is provided at the top for letting out odorous emissions, if generated in the filter. Media washing is done periodically depending on the grey water characteristics and quantity (Elmitwalli, Shalabi, Wendland and Otteroshi, 2007). After filtration, the next step in grey water treatment is ultraviolet disinfection (UV), which provides ultraviolet lamps as a precautionary barrier against pathogens. Finally, chlorine (Cl) residual is added to the recycled water to treat it and remove bad odour while in storage. Storage tanks can also be made of different materials e.g. concrete, steel, fibre glass, plastic or site built tanks (Tal, Sathasivan, Krishna, 2011).

However, the treatment process depends on the type and characteristics of the grey water produced at the local level. As the generic water treatment process may not be able to treat the grey water to the desirable quality, testing of the characteristics of grey water, and consequent selection of a cost effective and efficient treatment process is required.

A grey water treatment system consists of a couple of stages that include aerobic screening, multi-media filtration, ultraviolet disinfection and chlorination. Aerobic screening reduces insoluble material to manageable residue. Residue is discharged to sewer and the remaining grey water is collected into the second module. The multimedia filtration process is a physical process that largely separates suspended material from grey water, while ultraviolet radiation is a disinfectant against pathogens. Addition of chlorine for further treatment of grey water also removes odours.

2.8 Water challenges in South Africa

South Africa faces a numerous water related problems. First and foremost, fresh water is a scarce resource in the country. According to Stone (2012), there are a number of reasons for the scarcity of water in South Africa. Whereas in some areas of the country the cause is natural, it is man-made in other areas. (Fabriz, 2011) also state that some areas in South Africa experience shortage of water due to the fact that the country is prone to droughts. Other natural causes of water shortages include climate change which brings more water supply uncertainties, high surface runoff, high evaporation and transpiration (Eriksen, O‟brien and Rosentrater, 2010).

Humankind is also to be blame for the water shortage in South Africa. Van Vuuren (2012) identifies the poor location of dams as one of the critical issues that could be of help to alleviate water problems in the country. According to Hall, Leatt, and Manson (2011), water availability as well as human health is affected by the decreasing quality of water, dysfunctional municipal water infrastructure, increased water deficit, water and pollution.

According to Mainganye (2010) other ancillary factors that influence the water shortage of the country include lack of skilled human resources, illegal use of water, shortage and or inappropriate use of funds by municipalities. In support of the above points, Hall et al.

(2011) suggested that numerous factors such as illegal connections, urbanisation and population growth, contamination of existing water sources and leaking pipes have a bearing on water shortages in South Africa.

2.9 Water challenges in Witbank

Witbank faces a number of challenges associated with water supply to industries and domestic consumers. Due to the increase in demand of water over the years, the water supply from various sources in and around Witbank is lower than the requirement levels (Nagata and Funamizu, 2009). Despite the factor that demand for water outstrips supply, the infrastructure and technology used in distribution of water to users is very old (about 50 years) and obsolete (Van Rooyen, Van Niekerk and Versfeld, 2011). It is therefore difficult to keep up with proper maintenance of the entire water management system and as a result the entire system is very inefficient with significant distribution losses of up to 42% (Van Vuuren, 2013). However, Witbank Municipality does not have adequate funding to carry out proper maintenance, repairs and upgrades of water infrastructure within the area.

Coal operations in Witbank have had serious environmental effects such as high levels of water pollution and acid mine drainage (Singer, 2011). Mine water in Witbank is acidic and has a high metal and sulphide content, posing a danger to plant and human life. Witbank municipality still lacks effective measures to manage and control the problems related to AMD.It is reported that Witbank water is visibly of poor quality and many people in the area buy water for drinking purposes (Murphy, 2011). The poor quality of water in Witbank is also due to pollution of the streams (poor quality effluent discharged to the environment).

Numerous households in Witbank have unmetered water supplies which are difficult to manage and present difficulties in carrying out appropriate supply and demand audits for effective decision making purposes. Due to intermittent disruptions, water supply to households in Witbank is not reliable, which is an inconvenience to both domestic and industrial users.

Witbank Municipality suffers from skills shortage particularly in water engineering and related water management systems. Most of the technologists and engineers are not adequately equipped with skills required to implement new techniques and technologies in water management systems (Matsinhe, Juizo, Rietveld and Person, 2011). Therefore, poor technical skills affect the municipality's endeavour to provide a quality service that meets the expectations of the users. Other challenges with regards to water in Witbank include the following:

- Reliance on transporting portable water with water tankers,
- Distribution system not performing to design capacity,
- Inadequate human resources capacity and
- Overloading of systems

2.10 Strategies to address water challenges in Witbank

A number of strategies have been designed to address challenges that are faced with water in Witbank. The Municipality plans to refurbish its water treatment plant in eMalahleni. This is intended to improve the reliability of the network system, reduce the water losses and improve the quality of water supplied to users.

Other strategies that have been employed by the municipality to improve the water supply situation within the area are as follows:

- Establish partnerships with communities for installation of metered water supply (cost recovery)

- Improve on scheduled deliveries of portable water through water tankers
- Refurbish the dysfunctional water infrastructure components
- Increase number of water tankers

2.11 On-going research on grey water in South Africa

A lot of research on grey water is currently underway in South Africa. A study evaluating plant growth, soil characteristics and the microbiological quality of vegetable crops irrigated with domestic grey water in eThekwini Municipality district has recently been done. The findings indicated that grey water irrigation increased plant growth and crop yield, improved plant nutrient content and increased microbial loads on plants particularly *E. coli* and total coliforms (Pinto, Maheshwari and Grewal, 2010). However, grey water irrigation was also found to increase health risks associated with consumption of unwashed raw crops, but these risks could be reduced to acceptable limits by either washing and peeling, or cooking crops prior to consumption.

A study has also been done to identify grey water quality constituents. This study was conducted in accordance with South African and international guidelines for water quality. The main aim of the study was to identify the water quality variables likely to indicate whether grey water is suitable or unsuitable for particular uses. A long list of indicators was initially identified. However, it was felt that this list was too long for practical consideration and that it had high cost implications (Ridderstolpe, 2010). The list was reduced to 7 very relevant indicators which included E. coli, pH, boron, COD, oil and grease, total nitrogen and total phosphorus.

A study has been done to determine the contribution of cleaning products to grey water quality, within the context of detergent formulations used in South Africa. Unilever SA provided estimated concentrations of detergent products in laundry and washing grey water. The findings indicated that the major contributor of detergent products to potential adverse effects of grey water use for irrigation is sodium (Murphy, 2008). Sodium not only affects salinity and sodicity of soil, but also significant impact on plant growth, yield, and on soil structure (Naicker, 2008).

A treatment system combining primary and secondary treatment was piloted in the Hull Street Project, Kimberley (Ridderstolpe, 2010), and the Scenery Park Development, Buffalo City Municipality (BCM) (Whittington-Jones, 2010). The system comprised an above-ground mulch tower and a sub-surface resorption bed. Testing to date has indicated that the bulk of treatment occurs in the mulch tower, with a smaller proportion performed by the Infiltra and resorption bed (Naicker, 2008). However, this may have been the result of limitations in experimental design. Observational studies in Kimberley suggest that the combination of mulch tower and resorption bed successfully treats household grey water (Ridderstolpe, 2010).

2.12 Conclusion

To cover for the lack of fresh water, grey water can be used for diverse household purposes such as toilet flushing, gardening and irrigation, washing machines as well as other applications such as car washing, and firefighting. However, to make this a reality, the application of physical, biological and chemical treatment processes can be applied either individually or in combination is required to achieve desired quality levels. These treatment methods differ in terms of cost and recycling efficiency. Literature has uncovered that grey water also contains mineral resources such as calcium, iron, potassium, sodium, magnesium, cadmium, cobalt, copper, lead, tin and zinc. The availability of these resources is dependent on the source of the grey water, the activity and the quality of life of the water users. Despite the positives prospects grey water presents, it also presents numerous challenges. Firstly, grey water can be a health hazard as it can provide a breeding ground for mosquitoes and pathogenic microorganisms. Secondly it can contain excessive amounts of salts, total suspended solids, nitrogen, ammonia and phosphates that can be harmful to plant matter and cause changes in soil properties which can have dire consequences for plant and animal life. It has also been established that heavy metals with corrosive characteristics that have a damaging effect on the agricultural infrastructure and can be costly if left unattended are found in grey water. Consequently, based on the literature study on recycling perspectives of grey water for resource recovery that has been done, it is possible to recycle grey water for various purposes such as irrigation, car wash, flushing among other things. Theory also stressed that grey water contains mineral resources that can be recovered.

Studies that have been done in the South African context indicate that grey water mostly contain. E coli, pH, boron, COD, oil and grease, total nitrogen and total phosphorus. However, grey water from detergent products were found to have high levels of sodium that can adversely affect plant life if used for irrigation prior to further treatment. Studies in South Africa have also indicated that grey water irrigation improve plant growth and crop yield, plant nutrient content, and microbial loads on plants. On the other hand, grey water irrigation was also found to increase health risks associated with consumption of unwashed raw crops.

CHAPTER 3: STUDY AREA

3.1 Introduction

The study aims to examine the quality (impurities and nutrient content) of grey water generated in the study area and quantify the availability of different resources such as nitrogen, potassium and phosphorus which can be recovered from grey water. The study also aims to investigate the recycling of grey water under diverse simulated scenarios of individual and a combination of treatment processes and the re-use thereof for domestic and agriculture purposes in order to reduce the pressure on water demand. The abundance of coal deposits in and around Witbank, as well as the population and occupational profiles, water quality and water supply and demand of Witbank, present challenges to grey water treatment and the recycling process. This chapter presents relevant details on the study area (of Witbank in Mpumalanga).

3.2 Location of the study area

Witbank, also known as eMalahleni is a city that is situated on the Highveld of Mpumalanga, South Africa. The eMalahleni (Witbank) Local Municipality is in the Nkangala District Municipality of Mpumalanga province. The City of Witbank is about 112 kilometres South East of Pretoria.

Witbank is located along the railway line linking Pretoria to Maputo and serves as a transport gateway to the Mozambique port. Two national highways, the N4 from Pretoria and the N12 from Johannesburg converge at Witbank and then continue to Komatipoort, on the border of Mozambique (Figure 3.1). These routes form the Maputo Corridor, a strategically important alternative to the South African ports of Richards Bay and Durban on the Indian Ocean shores of the country.

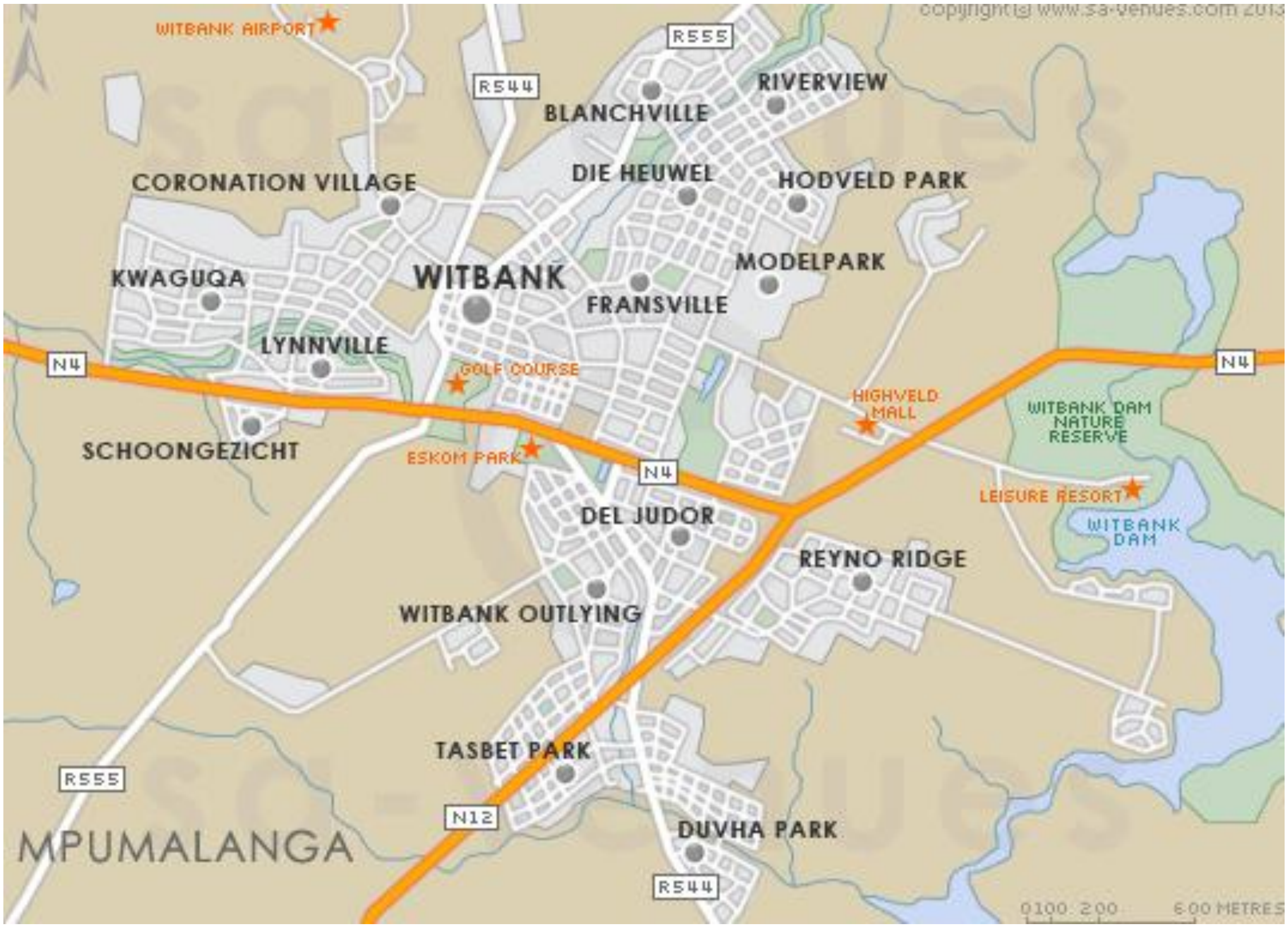

Figure 3.1: Location map demonstrating the position of the city Witbank in Mpumalanga Province

3.3 Population profile of the city Witbank

3.3.1 Population trends of Mpumalanga and the city Witbank town

According to the StatsSA (2012) report, both Mpumalanga province and the city Witbank have recorded significant population growth in the last two decades (Figure 3.2). The population size of Mpumalanga Province increased by 29.3% from 3 123 869 to 4 039 939 between the years 1996 and 2011 when the last census count was done. During the same period, the city Witbank also recorded a population growth of 6.7% to a total population of 395 466 (StatsSA, 2012). Van Vuuren, (2013) projected the population growth of Witbank at 512 600 by the end of the year 2017, mainly due to migration in search of employment opportunities in the Kusile power station, the steel manufacturing industry as well as secondary and tertiary industries in Witbank.

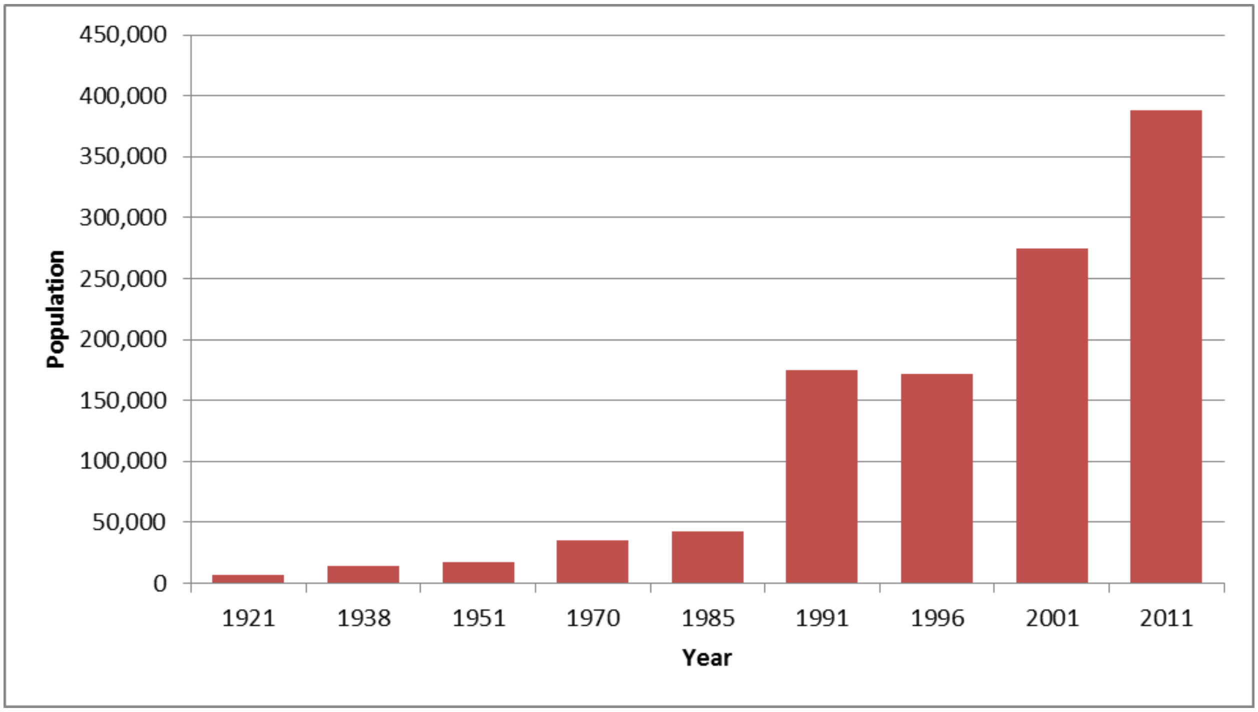

Figure 3. 2: Population growth of Witbank from 1921 to 2011

(Source: StatsSA, 2011)

3.3.2 Distribution of Witbank population according to gender and age

The statistics South Africa (2011) report that out of a total population of 395 466 for Witbank, there is a marginal difference between the number of males (49.4%) and females (50.6%).

Figure 3.3 below indicates the Witbank population distribution by age group according to the last census done in 2011. Figure 4.3 demonstrates that the Witbank population constitutes largely of young and able-bodied people. At the time of the census, the 0-39 age group constituted 77.2% of the total number of residents in Witbank, whereas the able bodied or working age group (25-54 years) was constituted 39.7%. However, the pensionable age (55 years and above) constituted 10.0% of the total number of Witbank residents as demonstrated in Figure 4.3.

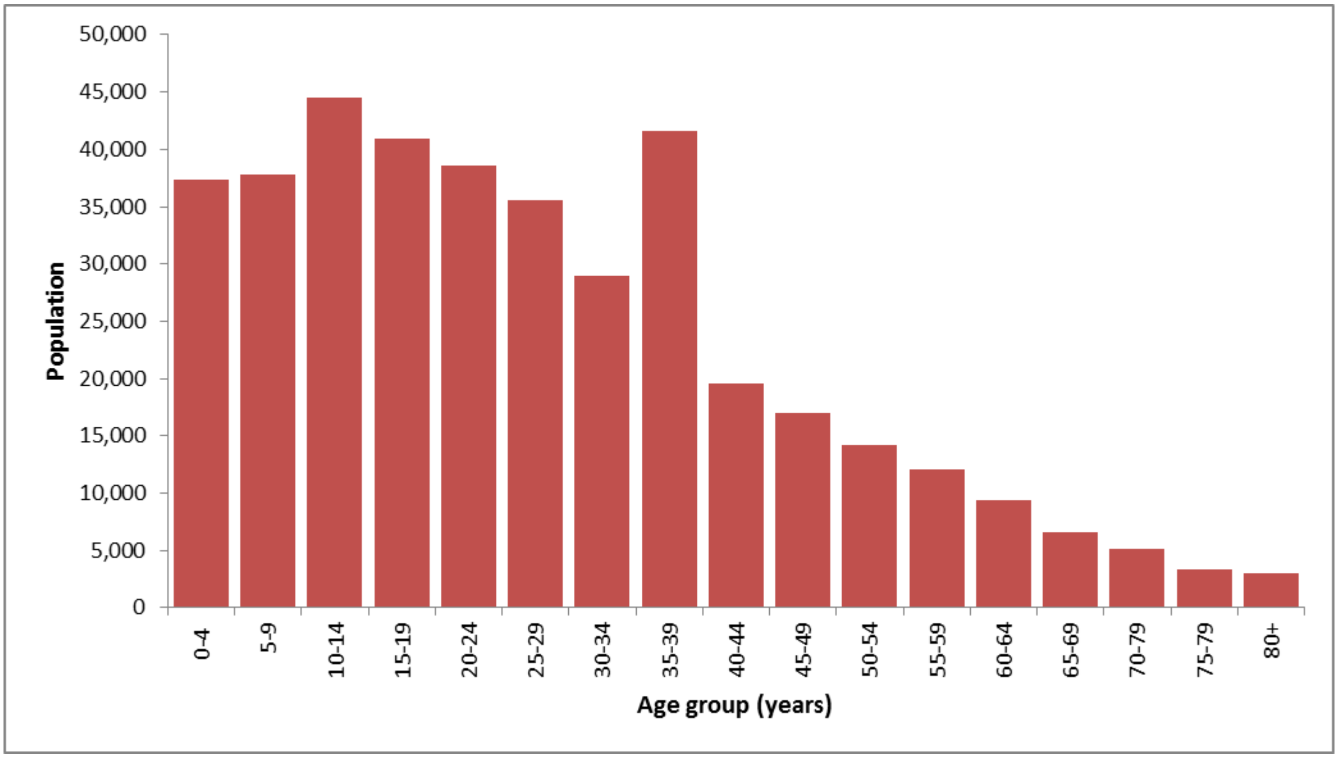

Figure 3. 3: Distribution of Witbank town population by age group

(Source: StatsSA, 2011)

3.3.3 Distribution of Witbank population by ethnic groups

The Witbank population distribution according to ethnic groups is demonstrated in Figure 3.4 below. According to the StatsSA (2011) census, Black Africans comprise about 48% of the total population in Witbank while the White community comprise about 48%. The minority groups such as Coloured, Asians and Others comprise about 2%, 2% and 1% respectively of the total number of Witbank residents.

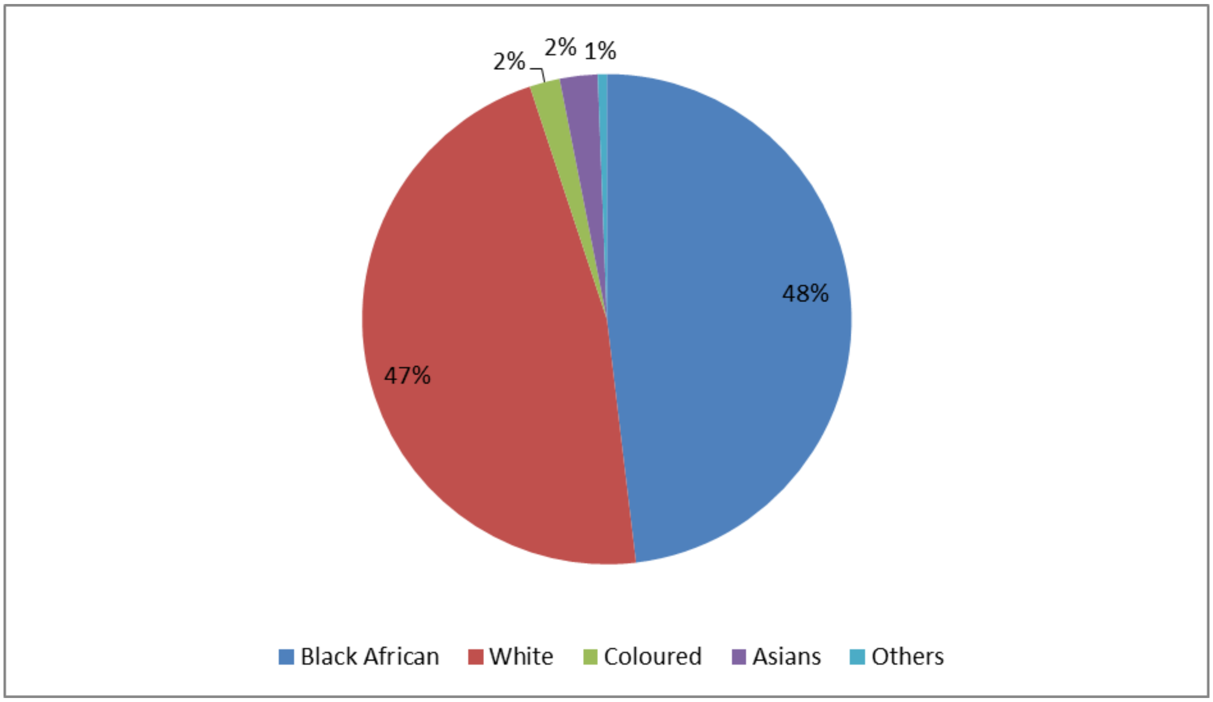

Figure 3.4: Distribution of Witbank population according ethnic groups

3.3.4 Distribution of Witbank population according to language spoken

The Witbank population distribution according to language spoken is illustrated in Figure 3.5 below. According to the StatsSA (2011) census, Afrikaans is commonly spoken among the White and Coloured community of Witbank. Whereas the Black population mainly speak Zulu and the Asians mostly English.

According to the 2011 census, the major languages spoken in Witbank were as followed: Afrikaans (48.8%), Zulu 23.1%, English 11.7%, Northern Sotho 5.2% and Swazi 3.0%.

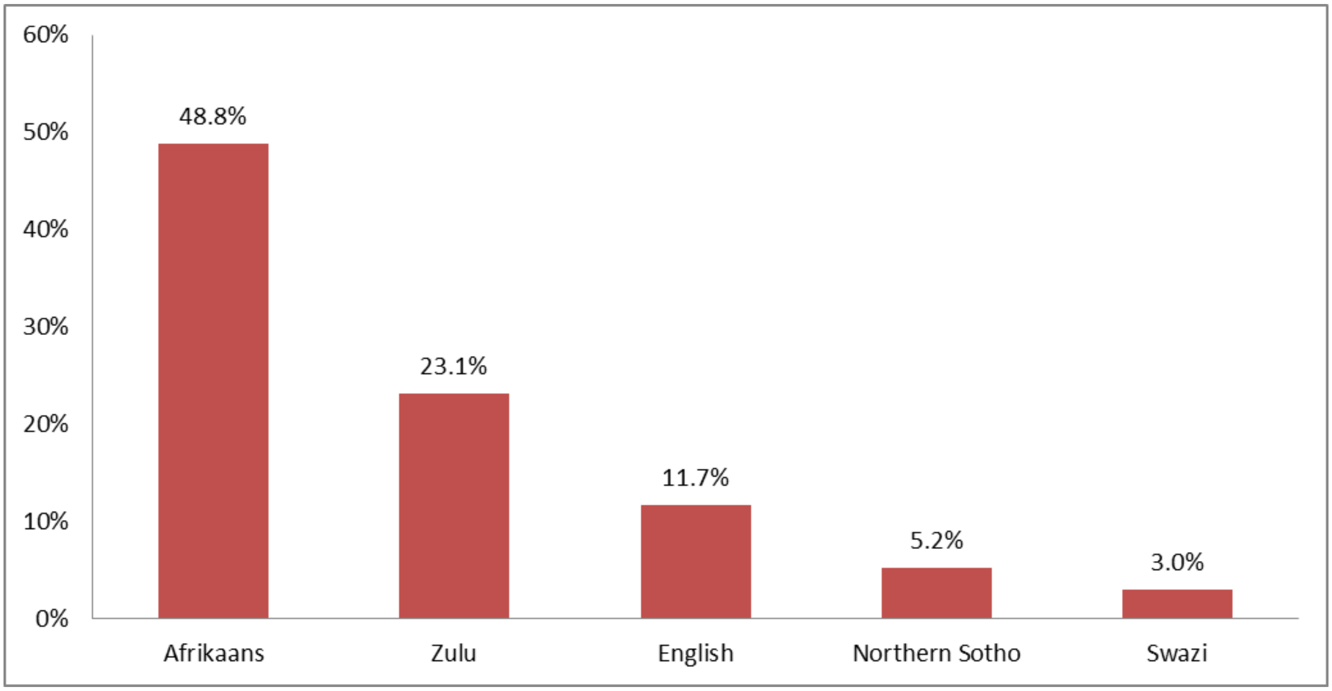

Figure 3.5: Distribution of Witbank population according language spoken

3.4 Economic Profile of the city Witbank

Witbank city has a total of 22 collieries in operation which provides significant employment to the local communities. The city has rapidly expanded over the years and has attracted international companies such as Anglo American, BHP Billiton, Evraz, Eskom, Exxaro, Joy, Komatsu, the Renova Group, SAB-Miller, SAMANCOR, Shanduka Beverages, Xstrata and Zenith among other strategic players.

Witbank city is seen as a mining and service centre for the surrounding region due to its strategic location on the Maputo Development Corridor and its proximity to Gauteng province which is the industrial hub of the country (CDE, 2009). The strategic location of Witbank attracts diverse business. Wholesale, retail trading, agriculture and finance, as well as social and personal services are the major highlights in the Witbank economy. Other supporting features to the Witbank economy include agriculture, animal husbandry, coal and gold mining, tourism and power generation, as well as proximity to former ‘homeland’ areas established during the Apartheid era (Centre for Development and Enterprise report, 2009). Business operations in Witbank are also supported by the relatively high demand from the local community who is largely employed in the formal sector and who grew phenomenally from 73 486 to 105 017 (42.3% growth) between 1996 and 2011 (StatsSA, 2011) as demonstrated in Table 3.1.

Table 3. 1: Employment figures for the formal sector

Census Year	1996	2001	2011
National total	8,208,455	8,520,863	10,594,638
Mpumalanga Province	603,825	629,566	740,077
Witbank	73,486	74,840	105,017

The informal sector also provides support to Witbank through employment of the locals. According to the Emalahleni Local Municipality Integrated Development Plan (2014), the informal sector has also grown significantly over the years and has helped in reducing the unemployment rate from 38,4% to 27,3%. This sector mainly covers manufacturing, construction, trade and transport as shown in Table 3.2.

Table 3.2: Employment figures for the informal sector

Sectors	Manufacturing	Construction	Trade	Transport
National Total	112 522	148 906	346 371	74 436
Mpumalanga Province	16 411	13 529	40 789	4669
Emalahleni	885	1036	3806	479

3.5 Main economic sectors of the city Witbank

According to the Emalahleni Local Municipality Integrated Development Plan (2014), Witbank’s economy forms the hub of Western Mpumalanga and contributes about 20%

to the Gross Value Add of the province. The contribution of coal mining, steel manufacturing, and energy generation to Witbank city and the country at large needs special mention and is discussed in brief below.

3.5.1 Coal Mining in Witbank

Coal mining is one of the largest industries operating in Witbank, and it produces about 80% of the country's coal to meet local and export markets (Blignaut, Nkambule, Riekert & Lotz, 2011). The open cast mining method is commonly used in Witbank to extract coal as the seams are shallow. However, in some areas within this city underground mining is applied depending on the distance of coal deposits to the surface.

A number of large international conglomerates operate mines in Witbank. The presence of Anglo-American, Exxaro, Sasol, BHP Billiton and Xstrata is noticeable and they are among the biggest producers in South Africa contributing about 80% to coal production in South Africa (Ebethard, 2011). According to Hall (2013), about 75% of local coal production is used domestically, the bulk thereof being used by Eskom, while exports constitute about 25% of production. Hall further stated that in 2011 the export of about 63 million tons of coal were exported largely to the EU, China and India -generated about R50,5 million in foreign revenue.

Despite the significance of coal mining in Witbank, there are lots of concerns around this business. The green policy that has been adopted by the national government poses a real threat to the operations of coal mines particularly when coal mining is perceived to be the main contributor to gas emissions. According to the Mining Weekly (2010) report, mining deposits particularly in the Witbank belt are dwindling. Coal operations in Witbank have serious environmental impacts such as spontaneous combustion of mines and tailings, air and water pollution and acid mine drainage

(Singer, 2011). Finally, poor rail transport service presents a hindrance to coal exports from Witbank. However, alternative business models such as possible private ownership and operation of rolling stock have been proposed but no tangible results have been obtained.

3.5.2 Iron and Steel production in Witbank

Evraz Highveld Steel and Vanadium form the basis of the steel industry in Witbank. According to Dednam (2013), the steel industry in the area produced about 0,8MT of steel products in 2008 which fell to about 600 000 tons in 2011. The fall in production is due to depressed export demand, competition from foreign importers, a lack of innovation or research and development and an acute skills shortage (Dednam, 2013).

Though most of the steel produced in the Witbank area are primary and semi- finished products in the form of slabs, the Witbank plant is adapted to mining of the iron ore with high vanadium content. Despite the fact that the iron and steel companies operating in the Witbank area are employing significant number of locals, there are concerns regarding their lack of engagement with the community, their weak adherence to pollution control standards and the poor quality of other products.

3.5.3 Energy generation in Witbank

According to Blignaut et al., (2011), out of the 224 million tons of coal produced each year in South Africa, some 53% is used for electricity generation. Most of this coal that is used for electricity production comes from the Witbank coal mines. Due to the strategic position of Witbank (which is closer to coal deposits), Kusile power station was situated in the locality of Witbank. Construction of the Kusile power station does not only provides employment to the local community but also generates the much needed energy to meet the national demand. Mines in the Witbank area also produce coke that is used as a reducing agent in iron and steel.

3.6 Social and environmental issues in Witbank

3.6.1 Social concerns in Witbank

The sustained economic growth experienced in Witbank over the years has attracted scores of people from other provinces as well as neighbouring countries particularly Swaziland and Mozambique. This has led to a significant increase in population that has put lot of pressure on basic needs. According to Van Huyssteen & Botha (2008), service delivery in and around Witbank has not been able to keep pace with the demand and an acute housing shortage has arisen that is reflected in the informal settlements, illegal guest houses and rental rooms throughout the city.

However, according to John (2012), Witbank's economic growth has had positive benefits to the community. John (2012) showed that despite the increase in population of the city, the unemployment rate has decreased, the Human Development Index (HDI) has steadily improved and with an increase in the level of education and a decrease in the number of illiterate people. The HIV prevalence rate among pregnant women is high at 36.1% and 22.5% among the rest of the population (StatsSA, 2013). Due to the long term health effects of mining, some workers have developed chronic illnesses such as sinus, chest and lung infections. Substance abuse is a growing concern in Witbank and is putting a lot of pressure on the rehabilitation centres.

3.6.2 Environmental concerns in Witbank

There is an ever existing risk in Witbank of underground fires caused by oxygen entering the underground mines which contributes to the spontaneous combustion of coal (De Lange, 2011). Toxic chemical elements and compounds such as arsenic and mercury as well as concentrations of toluene, benzene and xylene are products contributing to coal combustion in the underground mines. Finally, there is lot of air pollution in Witbank that causes health issues such as asthma and bronchitis and has a detrimental effect on the vegetation cover in the area (Singer, 2011).

3.7 Water supply and demand

Since Witbank is one of the fastest growing urban areas in South Africa, the city is faced with challenges of meeting the increasing demand for clean drinking water. Witbank area has been experiencing an average increase in water demand of 3.5% per annum (Hodgson, 2008). The Emalahleni Local Municipality, the statutory local water service authority for Witbank, already exceeds its licensed abstraction of 90 ML/d from Witbank Dam by 11 ML/d. By 2030, the municipality's water demand is forecast to be 50% higher at 180 Ml/day (Gunther et al., 2006).

The Olifants River supplies large portions of water to communities in and around Mpumalanga. Table 3.3 shows the supply capacity of the Olifants River water management area as at 2016. Table 3.3 indicates that about 52% of the Olifants River water is supplied from the Upper Olifants while the Middle Olifants River supplies about 39% of the total. Steelpoort and the Lower Olifants River are the least suppliers of water with a combined total contribution of about 21%. Furthermore, about 53% water of the Olifants River water management area is supplied from the surface while about 13% is supplied from the ground. On the other hand, about 6% of the water is used for irrigation, 5% for urban purposes and 2% for industrial use- largely supplying water to mining companies.

Table 3.3: Water supply capacity of the Olifants River water management area as at 2016

Olifants WMA Year 2016 water availability (million m^3 / a)								
	Natural resources		**Usable return flow**			**Total local yield**	**Trans-fers in**	**Grand Total**
Sub-area	**Surface water**	**Groundwater**	**Irriga-tion**	**Urban**	**Mining & Bulk**			
Upper Olifants	223	5	2	39	5	274	197	470
Middle Olifants	115	81	39	6	1	242	105	346
Steelpoort	48	16	3	1	1	70	0	70
Lower Olifants	85	13	6	2	9	115	1	116
Total	472	114	51	48	16	700	198	898

Table 3.3 above compares the water supply capacity and demand within the Olifants River water management area as determined in the year 2016. It shows available water, water requirements and the balance of the projected supply and demand. Table 3.4 below shows that in the year 2017 the demand for water within the Olifants River water management area outstripped the water supply by 266 million cubic meters. The largest deficit of 122 million cubic meters was recorded in the Middle Olifants while the Upper Olifants River had the least deficit of 30 million cubic meters. The negative balance indicates that there was no spare capacity to meet the demand.

Table 3.4: The water supply capacity versus demand of the Olifant's River Management area supply at 2017

Sub-area	Available water			Water requirements			Balance
	Local Yield	Transfers in	Total	Local requirements	Transfers out	Total	
Upper Olifants	238	171	409	336	103	439	-30
Middle Olifants	210	91	301	419	3	423	-122
Steelpoort	61	0	61	102	0	102	-41
Lower Olifants	100	1	101	175	0	175	-74
Total	609	263	872	1,033	9	1,041	-266

Witbank Dam is the main source of water for the municipal eMalahleni area. On a daily basis up to 100 mega litres (ML) of water is purified from the dam. The municipality further receives 10ML water per day that is purified at Ga-Nala via the Usustu water scheme and 2ML from Rietspruit. The Wilge power station is supplied by Eskom at 4ML per day. Witbank Dam serves the city as well as the western suburbs such as Ogies, Clewer and Phola. This supply is supplemented with water sought from Anglo at an average of 16ML per day. The Olifants Dam also supplies these communities.

Table 3.5 below shows the projected water supply and demand per household in Witbank from the year 2012 up to the end of 2017. It also indicates the number of households that are supplied with water, the annual water demand (in mega litres), the annual demand per household (in mega litres), annual water supply (in mega litres) in

Witbank, supply per household (in mega litres) and the deficit per household (in mega litres). Table 3.5 also shows that the annual increase demand for water per household in Witbank is much higher than the annual supply thereof per household. In the year 2012, the water supply per household exceeded the demand by 0.097 ML. However, by the end of 2017, the demand per household exceeded the supply by 0.150ML. Based on the current trends, it can thus be concluded that if no solution is provided to the deficit in water supply, is only going to increase as the demand continues to increase.

Table 3. 5: Projected water demand versus supply per household in Witbank

Year	Households (H)	Demand (ML)	Demand/H	Supply (ML)	Supply/H	Deficit/H (ML)
2012	119874	36,573.29	0.305	48180	0.402	0.097
2013	122271	51,202.61	0.419	48180	0.394	-0.025
2014	124717	51,202.61	0.411	48180	0.386	-0.024
2015	127211	54,184.94	0.426	48180	0.379	-0.047
2016	129755	61,770.83	0.476	48180	0.371	-0.105
2017	132351	67,982.35	0.514	48180	0.364	-0.150

3.8 Water challenges in Witbank

Coal mining, steel production and energy generation have had a serious impact on the environment. Even though a lot of mines in Witbank are abandoned they still drain acid water. This results in the continuous increase in the salinity and sulphate concentration of the water from the Witbank dam. Consequently, the recommended sulphate concentration level of 200mg/L for domestic use is frequently exceeded (McCarthy, 2010). Eskom has also found the water sourced within Witbank to be of poor quality for use in their power stations and has resorted to importing water. Other water related challenges within the study area include;

- Water quality in Witbank is a recurring challenge. The quality of water does not comply with SANS241:2014 requirements.
- There is a lack of maintenance of the water infrastructure within Witbank and operational procedures are hardly followed by the technical staff.

- The water infrastructure in Witbank is obsolete and can hardly cope with the existing demand
- Leaking waste water pipes were contaminating potable water through seepage. Water quality tests found high levels of E colli and coliforms in the water that were well above the SANS241:2014 requirements (Nagata and Funamizu, 2009).
- Water requirements in and around Witbank already exceed water availability. The situation is particularly serious in the Crocodile sub-area, where the strongest potential for economic growth exists, which will exacerbate the existing shortages (Omami, 2011).
- Continued growth of the urban and industrial areas of Witbank and Middelburg is stretching the deficit in the water supply demand for the area (Misra, Patel, & Baxi, 2009).
- There is little potential for further large scale development of local water resources in Witbank and surrounding areas. Any additional water required for power generation will have to be sourced from outside the existing water management area (McCarthy, 2011).

3.9 Water Quality in Witbank

Biological, microbial and chemical concerns with regards to the quality of water in and around Witbank have been raised. A detailed discussion of these concerns follows below

Biological / microbial: substantial – volumes of return flow from the sewage treatment plant in the Loskop Dam catchment, has been identified as a cause of eutrophication in the surrounding areas. The potential risk-of microbial or faecal contamination of the surface and groundwater of the Elands River catchment is high.

Chemical / mineralogical: The mineralogical surface water quality is generally good in the Upper Olifants and Wilge River catchments. It deteriorates slightly in the Elands River catchment and in the Olifants River downstream of Loskop Dam. The concerns about water quality on the Olifants and Klein Olifants River catchments include high concentrations of dissolved solids (TDS) and sulphates, low pH of about 4.3, and at times high concentrations of iron, manganese and aluminum as a result of mining activities (Omami, 2011). It was found that TDS and sulphate concentrations increased where streams pass through mining areas. In the Klipspruit catchment, major concerns have been expressed about pH, TDS, sulphate, aluminum and manganese. The Wilge River catchment was largely unpolluted, with low TDS and sulphate concentrations, and no concerns about water quality were noted. In the Olifants River between Witbank Dam and Loskop Dam, concerns were noted about low pH, high EC and high sulphate concentration in the Spookspruit, but Loskop Dam appeared to meet guidelines values, - probably as a result of the Wilge River improving the inflowing water quality into Loskop Dam.

3.10 Water treatment plants in Mpumalanga

There are a total of about 14 sewage water treatment plants (STP) with varying capacities in Mpumalanga Province. These plants use different methods for the treatment of wastewater and sludge. Generally, the treatment process depends on the type and characteristics of the grey water produced at local level. Therefore, generic water treatment process may not be able to treat grey water to the desirable quality, which requires appropriate selection of the test method for characterisation of the grey water and the consequent selection of a cost effective and efficient treatment process.

Common treatment methods that are applied in Mpumalanga Province include sedimentation, mesophilic or thermophilic anaerobic digestion, composting, storage or a combination of these methods. The treatment processes have an impact on the physicochemical parameters of the final effluent such as the biochemical oxygen demand (BOD), chemical oxygen demand (COD), electrical conductivity, total hardness, alkalinity, dissolved oxygen, some metals and non-metal ions. The sewage treatment plant in Witbank uses trickling filters (the anaerobic digestion treatment process). A similar treatment plant is in use in Nelspruit.

Witbank, Nelspruit and Lydenburg municipalities use the anaerobic digester treatment process to treat water. The other municipalities in Mpumalanga use activated sludge and ponds or trickling filters to treat water for the area. Only Malelane uses a pond treatment process for treatment of water. A summary of treatment plants, treatment processes being used and capacity of the treatment plants in Mpumalanga is presented in Table 3.6.

Table 3. 6: Treatment processes used in Mpumalanga Province Water sources

Name	**Treatment Processes**
Malelane	Ponds
Matsulu	Activated sludge
Kanyamazane	Ponds and trickling filters
Sabie	Activated sludge
White River	Activated sludge
Nelspruit	Anaerobic digestion, trickling filters (4), activated sludge, maturation ponds
Machadodorp	Activated sludge and ponds
Waterval Boven	Trickling filter, activated sludge
Belfast	Activated sludge and ponds
Dullstroom	Activated sludge and ponds
Hendrina	Trickling filters, activated sludge and ponds
Middleburg	Activated sludge and ponds
Witbank	Trickling filters (anaerobic digesters)
Lydenburg	Trickling filters (3 and one in construction), ponds (anaerobic digesters not working)

Table 3.7 demonstrates the water catchment areas in and around Mpumalanga, the feeder dams, as well as water storage capacity- and yield of each dam respectively.

Witbank Dam- with a storage capacity of 104.14 million cubic meters – is not only the biggest municipal dam, but also one of the biggest dams in the Southern Hemisphere. It is located on the Olifants River near Handrina and is the main source of water for Witbank communities. Witbank Dam mainly supplies water for municipal and industrial purposes. Both the Olifants and Inkomati catchment areas are important water management areas within the Witbank communities.

The Olifants River WMA consists of the Upper Olifants, the Steelpoort and the Middle Olifants water management areas.

- The following important rivers drain this area: The Klein Olifants from the east the Rietspruit, Steenkoolspruit and Viskuile from the south; and the Wilge and Koffiespruit from the west. The confluence of the Wilge and Koffiespruit flows into the Olifants River before Loskop Dam.
- The Steelpoort River drains a large area in the east, rising near Belfast and Lydenburg.
- The Moses and the Elands Rivers also flow into the Olifants River before the Arabie Dam making up part of the Middle Olifants sub-WMA. The WHR falls within this sub-area.

Several major dams of note within vicinity of the study are include;

- Witbank and Middelburg dams, which meet the urban and industrial demands of the Witbank and Middelburg centres;
- Bronkhorstspruit Dam which supplies Bronkhorstspruit and the WHR in the Elands River catchment with water for domestic and industrial use. There is also a supply for irrigation;
- Rhenosterkop Dam which supplies water for domestic use to the WHR and water for irrigation;
- Loskop Dam which is primarily used to supply irrigation water to the Loskop Irrigation Board. Some water is supplied to the WHR for domestic use.

Table 3. 7: Main dams in and around Mpumalanga

Name	Live Storage Capacity (10^6 m^3)	Firm Yield (10^6 m^3/a)	Owner
Upper Olifants Catchment			
Doornpoort	5.22	Minimal	Private
Middelburg	47.90	12.90	Municipality
Rietspruit	4.50	2.40	Private
Trichardtsfontein	15.20	112.70	DWAF
Witbank[1]	104.14	30.70	Municipality
Wilge River Catchment			
Bronkhorstspruit	58.90	19.00	DWAF
Wilge River (Premier Mine Dam)	5.04	5.70	Private
Elands River Catchment			
Rhenosterkop	204.62	8.90	DWAF
Olifants River Catchment between confluences with Wilge and Elands Rivers			
Loskop	348.10	145.20	DWAF
Rooikraal	2.12	0.64	DWAF
Steelpoort River Catchment			
Belfast	4.39	2.04	Municipality

3.11 Conclusion

Witbank is one of the busiest business hubs of Mpumalanga province. It has a diversified economy that covers mining, iron and steel manufacturing, generation of electricity, construction and agriculture among other economic activities. The positive aspect of Witbank's vibrant economy for the community includes the creation of employment and earning the country much needed foreign currency. Witbank's strong economy continues to improve the quality of life of the locals and has significantly aided in the improvement of their level of education as well. Despite these positives, countless concerns have been raised on the acid drain water, underground fires, water and air pollution and prevalent health issues that are associated with mining such as asthma and bronchitis. All of these experienced in Witbank present unique challenges to the grey water treatment process.

CHAPTER 4: METHODOLOGY

4.1 Introduction

Since Witbank is a mining town some tests that have been carried out have shown high acidity levels and heavy metal content. An experimental study was therefore sought to examine the quality (impurities and nutrient content) of grey water generated in Witbank the city in Mpumalanga province, South Africa and quantify the availability of different resources such as nitrogen, potassium and phosphorus, which can be recovered from grey water. Furthermore, the study sought to process grey water under different simulated scenarios of individual and a combination of treatment processes to comprehend the serviceability and re-use of the processed grey water.

Prior to undergoing any treatment processes, the grey water samples were tested in the laboratory for characterisation of the water quality in terms of turbidity, pH, macro-pollutants (total, suspended and dissolved COD, TOC), nutrients, volatile fatty acids, trace elements, metals, chloride, nitrite and nitrate concentrations. The availability of nutrients such and nitrogen, phosphorous and potassium – in the water was evaluated by using relevant laboratory tests. In addition, a survey of the water and grey water scenario in the city was conducted at household level.

This chapter discusses the applicable methodology that was used to recycle grey water and also recover vital nutrients. Aspects of the methodology that are discussed in this chapter include data collection, materials and methods and data analysis.

4.2 Data requirements

This study required material in the form of untreated grey water from bathrooms, showers, kitchens, laundry and sinks sourced from domestic water users in Witbank for experimentation. The experimental data required for the included the physical quality of the grey water determined by parameters such as pH, total suspended solids, turbidity and conductivity, the chemical characteristics of untreated grey water in terms of COD, orthophosphate, oil, grease, soap, dissolved Iron and Manganese; and the operational alert characteristics of untreated grey water- in terms of Aluminium, Alkalinity, Calcium, Chloride, Potassium, Sulphate and Sodium. Data on - Finally, resource content and microbiological determinants in untreated grey water from Witbank households were also essential for the study. Whereas resource content data requirements included Nitrates, Nitrites, Ammonia, Nitrogen and Phosphorus the data requirements for microbiological determinants included E-coli, Total Coliforms and Heterotrophic Plate Count.

The physical quality of the grey water, its chemical characteristics, as well as operational alert characteristics, the resource content and microbiological determinants for treated grey water under different simulated scenarios of individual and a combination of treatment processes were also essential for the study.

A grey water survey- in the form a questionnaire was also conducted among Witbank households to collect data. The household survey data included general household information (house type, income, occupation and number of people in the house), available services (water use of detergents and sanitation type) and grey water management (perception of its re-use and disposal method).

4.3 Data collection

Experimental - as well as household data were collected for the study on the treatment of grey water and the recovery of resources. A detailed discussion of the processes followed in the collection of both the experimental –and household data, is provided in the sub-sections below.

4.3.1 Experimental data collection

Grey water from bathrooms, showers, kitchens, laundry and sinks were collected from 100 domestic water users in business district (central areas), upscale development, township and neighbourhoods (city) of Witbank in Mpumalanga Province. The plan of the study was to collect and analyse grey water samples across the four seasons (in order to understand the variability in quality of grey water) as follows:

15 March to 15 April [autumn]

15 June to 15 July [winter]

15 October to 15 November [summer]

15 December to 15 January [summer plus festive period]

A total of 100 domestic water users in Witbank were randomly selected from the eMalahleni Municipality database to participate in the study. Domestic water users were subdivided into 4 clusters so that each cluster was made up of 25 users. Each cluster was linked to one of the 4 seasons that compromised autumn, winter, summer and the festive period. In each season, 10 litres of grey water samples were collected from each user in the morning into acid rinsed, polyethylene containers. Since the laboratory officially closed early in the day, the samples were collected only in the morning, to avoid storage problems. Samples were labelled using waterproof markers and were immediately taken on ice in insulated containers to the laboratory. Once in the laboratory, 5 litres from 10 users were mixed into a 50 litre storage tank (composite sample). Immediately after mixing, 500 millilitres of grey water was sampled for immediate characterisation by analysing grey water in terms of pH, macro-pollutants (total, suspended and dissolved COD, TOC), nutrients, volatile fatty acids, trace elements, metals, chloride, nitrite, nitrate concentrations, phosphorous and potassium (Figure 4.4). Each test procedure was repeated more than 5 times to obtain consistency of result.

4.3.2 Household data collection

A standardised grey water survey questionnaire was used to gather household data from upscale, business district (central), township and neighbourhood (city) areas of Witbank. The household survey questionnaires assisted in collecting vital information for the research. A total of 100 household- units, which were randomly sampled from the eMalahleni Municipality database were targeted for conducting the survey. Where possible, meetings were held with relevant officials and community leaders in the area to discuss the aims of the research as well as the expected outcomes.

In each sampled household unit being visited, survey was conducted on the current grey water quantities, as well as the water management and- activities of the occupants. In additional on local practice with regards to water use and management was also examined to determine the impact on grey water disposal and use. Data on the average income, water consumption, grey water production values, dwelling type, - and water supply each sampled household unit were collected by means of questionnaire that was as following;

General house hold information

- House type
- Income
- Occupation

- Number of occupants in the house

Available services

- Sanitation type
- Distance to water sources
- Water use
- Detergents use

Grey water management

- Disposal method
- Perception on use

The volumes of grey water consumed were calculated from the recorded amount of water consumed per house hold. In the absence of any formal metering, the figures for water consumption were based on estimates given by the occupants themselves (usually by the number of buckets of water collected during each day). On the other hand, information on water supply was obtained from the eMalahleni Municipal database.

4.4 Equipment

A variety of equipment was used for the grey water recycling and resource recovery processes. The equipment being used included the following;

Plastic containers and glass beakers: Five litre plastic containers and glass beakers were used in this experiment (Figure 4.1). The 5 litre containers were used to collect and transport grey water from domestic users (shower, bath, laundry machine) to the laboratory while glass beakers were used to measure the volume of samples from the collected grey water prior to and after treatment.

Figure 4. 1: Plastic containers and glass beakers

4.4.2 Other equipment

Other equipment employed for treatment of grey water included the following;

- Atomic Absorption Spectrometer (for analysis of trace metals)
- Ultraviolet spectrophotometer (for analysis of nutrients)
- Refrigerator for storage and preservation of grey water
- Filtration component to remove fine flock material,
- Ultraviolet disinfection unit, and
- Chlorination compartment

Figure 4.2 below shows the absorption spectrometer that was used for the analysis of trace metals.

Figure 4. 2: Atomic Absorption Spectrometer

The atomic absorption spectrometer shown in Figure 4.3 below was employed for analysis of trace metals.

Figure 4. 3: Atomic absorption spectrometer

A refrigerator (Figure 4.4) below was used to store and preserve grey water samples for the study.

Figure 4. 4: Refrigerator for storage and preservation of grey water

An illustration of the ultraviolet spectrophotometer that was used for the analysis of nutrients is presented in figure 4.5.

Figure 4. 5: Ultraviolet spectrophotometer

The Ultraviolet steriliser illustrated in Figure 4.6 below was used for killing bacteria.

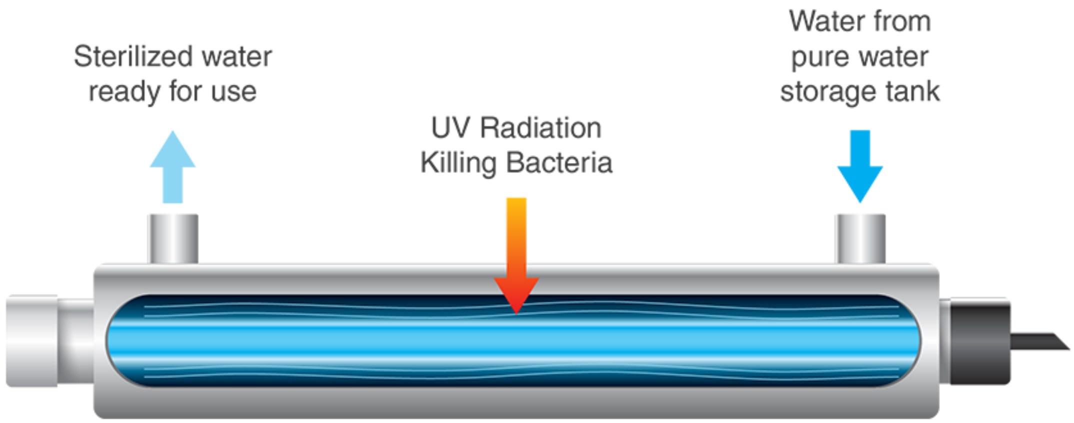

Figure 4. 6: Ultraviolet steriliser

Typical examples of samples used during the grey water treatment process are indicated in Figure 4.7.

Figure 4. 7: Samples used during grey water treatment process

Figure 4.8 presents an additional illustration of samples being used during the grey water treatment process.

Figure 4. 8: Other samples used during the treatment process of grey water

MMF and glass beakers being used during the treatment process of grey water are illustrated in Figure 4.9 below.

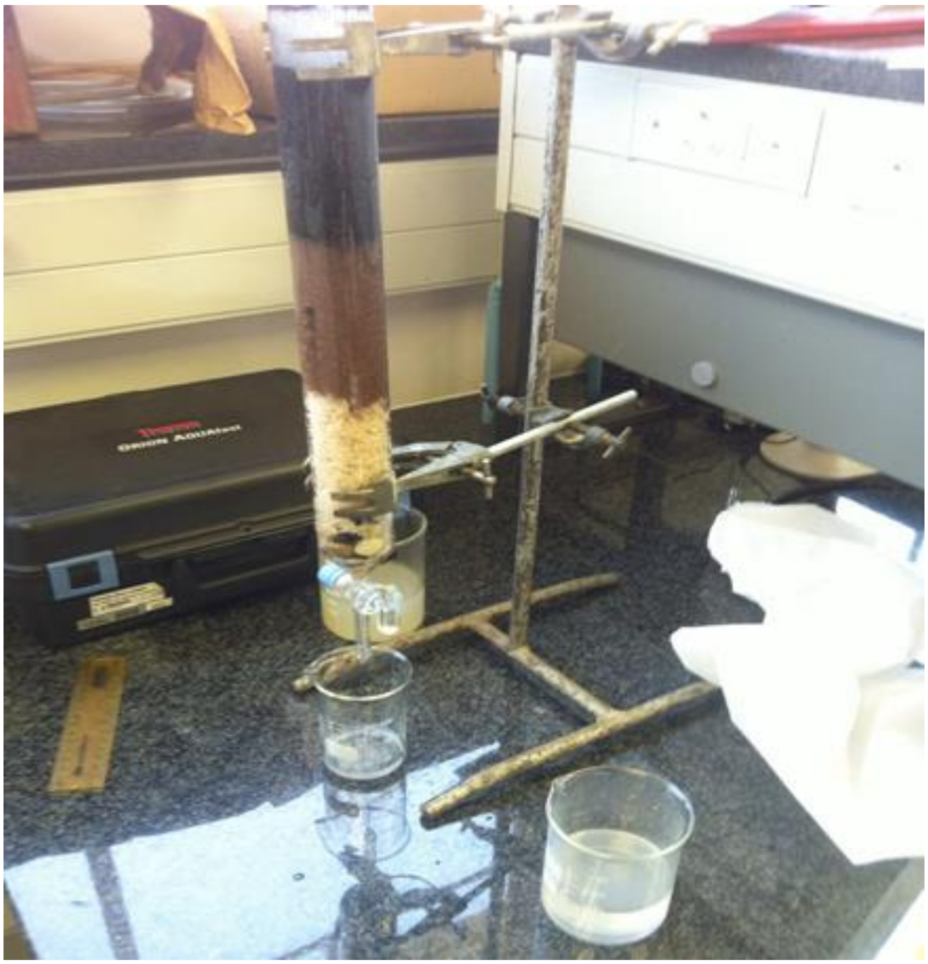

Figure 4. 9: MMF and Glass beakers

An illustration of the apparatus employed for aerobic screening during the grey water treatment process is presented in Figure 4.10 below.

Figure 4. 10: Apparatus for aerobic screening during the grey water treatment process

4.5 Method

There are various methods that can be used for conducting a research. However, in this study, two separate methods that complement each other were employed. An empirical study through laboratory experimentation was used in order to examine the quality (impurities and nutrient content) of grey water as well as the quantities of various resources such as nitrogen, potassium and phosphorus, which were recovered from grey water. Laboratory experimentation also included the processing of grey water under different simulated scenarios of individual and a combination of treatment processes to comprehend the serviceability and re-use of the processed grey water.

In addition, the life style of participants or households in Witbank (which is assumed to have an effect on the quality of grey water) was evaluated by means of a survey using a questionnaire as instrument. The survey profiled 4 distinct household clusters which included townships, upscale developments, and business district and neighbourhood areas of Witbank.

4.6 Sample storage

If the remainder of the sample could not be analysed immediately, the samples were kept stored at around 4oC for a period of not more than 24 hours for analysis of Biochemical oxygen demand (BOD), Total suspended solids (TSS), Nitrate, and Orthophosphate. Wherever possible, Environmental Protection Agency (EPA) approved standard methods were employed, but due to the high sample volumes, some EPA approved test kits for grey water by the Housing Authority of the City of Houston (HACH) were also employed. Quality control standards, including blanks and spiked samples, were used.

4.7 Experimental investigations

Grey water was subjected to chemical and physical tests before as well as after the treatment process. The Mpumamanzi laboratory was used for conducting all the tests for the study. The details of the tests that were done are discussed below.

All chemical analyses of untreated and treated grey water samples under different simulated conditions (Figure 4.11) were carried out as described in the Standard Methods (APHA, 2005), using its adapted versions for the Hach methods or in accordance to the suppliers' instructions. Measurement of the pH of treated and untreated grey water samples were done with a pH probe and meter (Corning Model 450, NY, and USA). On the other hand, COD was determined by calorimetry after reacting 2mL of the sample with potassium dichromate at 150°C for 1 hour. Whereas, suspended COD was defined by a particle size of >12–25 µm (Whatman Grade 589, black ribbon filter), dissolved COD was defined below a particle size of 0.45 µm. Total solids in grey water were determined by drying for 24h at 70°C and were analysed using a TOC-5000A. Turbidity of grey water was measured with a HACH 2100N turbidimeter after being dispersed in an ultrasonic bath. In this study eight simulated scenario, (illustrated in Figure 4.11), were used individually and in various combinations. These combinations included Aerobic Screening (AS) and Ultraviolet rays (UV), AS and Chlorination (CL), Multimedia Filtration (MMF) and Ultraviolet rays (UV), MMF and CL, MMF, AS and CL, MMF, AS and UV and MMF, AS, UV, and CL. Simulated scenarios were used as this enables identification of combination option(s) that will give the best results in terms of costs and quality of grey water that can meet expected standards for domestic service use.

Metals and trace elements such as Al, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, P, Pb, S and Zn were determined by Inductively Coupled Plasma Mass Spectrometry while ammonia nitrogen was determined using an Ammonia-sensitive probe that was connected to the pH/ion meter. The phosphorous and potassium levels were obtained by calorimetry based on the Amino acid- as well as the Tetraphenylborate method and by means of a spectrophotometer. Detailed discussions of the experimental methods being used in this study to carry out chemical tests are presented in the subsection that follows later.

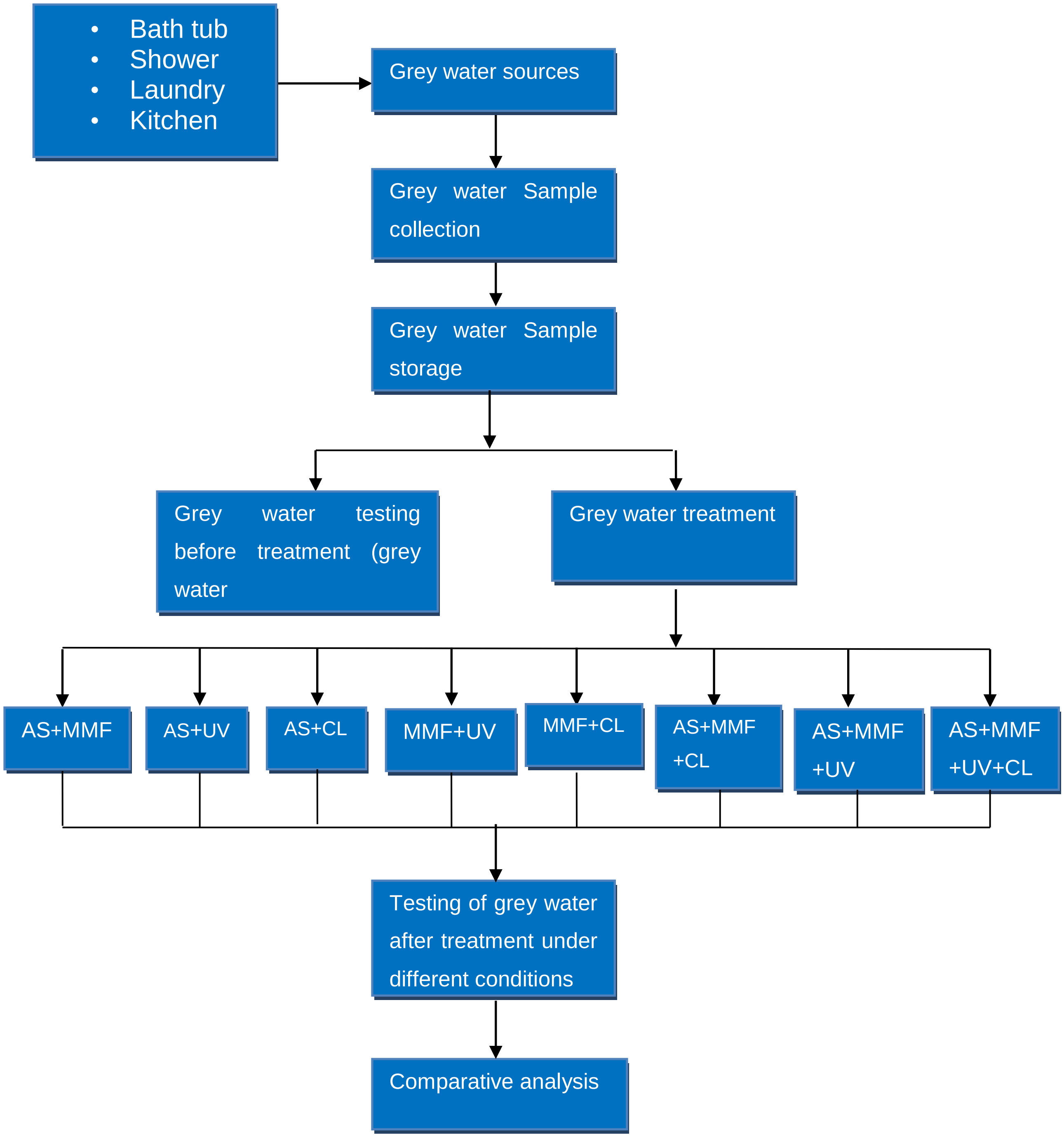

Figure 4.11: Grey water Collection and Treatment process flow diagram

Note: Aerobic Screening (AS) and Ultraviolet rays (UV), AS and Chlorination (CL), Multimedia Filtration (MMF) and Ultraviolet rays (UV)

The bulk of the untreated grey water that was collected from users was subjected to physical and chemical treatment processes (Figure 4.12). The physical treatment processes involved aerobic screening and multimedia filtration.

The multimedia filtration process (Figure 4.12) was performed by using gravity to pass water through a porous medium of stone, a granular bed of varying sizes and sand (Najee, 2007). The Multimedia filtration process is shown in Figure 4.12. The detailed experimental methods that were applied to carry out physical tests are covered in the subsection that follows below.

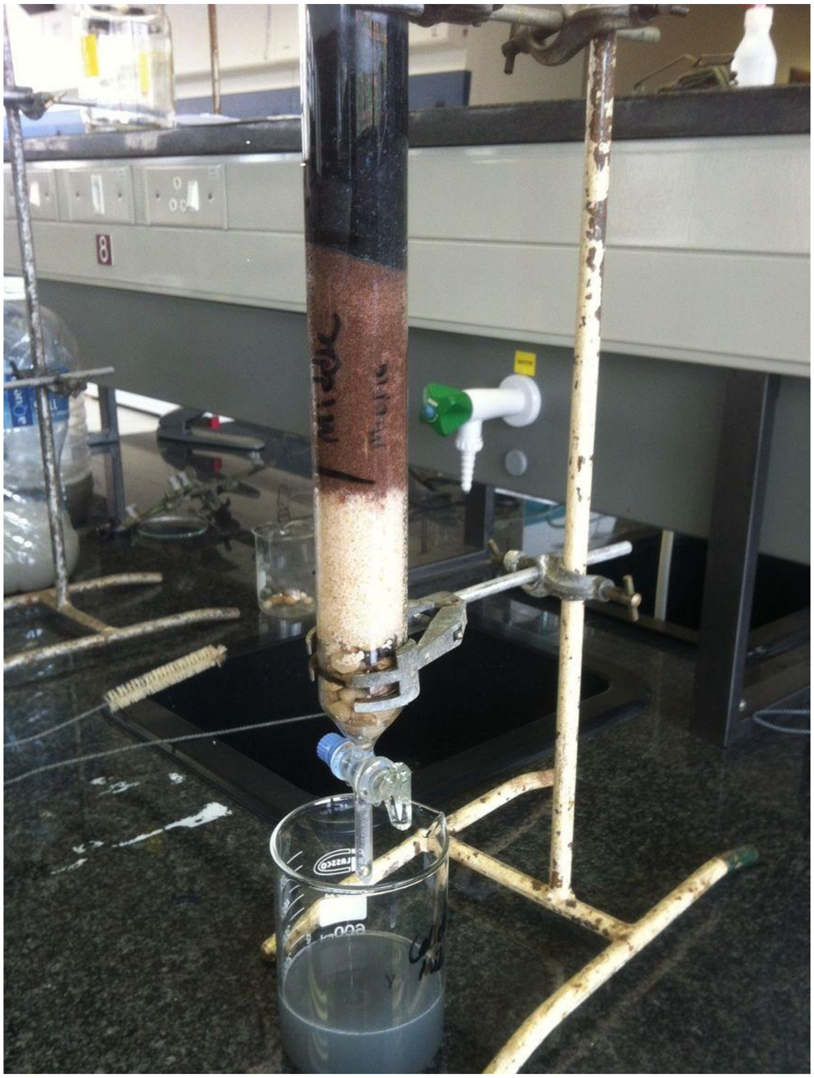

Figure 4.12: Multimedia filtration process

The filtration process was specifically done as it is perceived to be the most effective method for the removal of larger pathogens, such as protozoa, followed by bacteria, and then viruses, due to size exclusion. At the upper layer of the designed filter was sawdust, while the bottom layer was a bed of sand, supported by a 0.05m bed of gravel. The filtration rate was set at 0.047m3/h. The filtration media consisted of a 0.55 mm layer of river sand with a, specific gravity of 2.65 and a uniformity coefficient of 1.6 (Enugu State Water Corporation, 2010). The sawdust had a specific gravity of 1.8 with a particle size notation of -40/+60 (Nwafor, 2010). These choices of media depth of the sawdust and sand used in this experiment were guided by the filter media specification recommended in the (AWWA, 2001).

Grey water from a collection tank was fed to the surge tank by means of a 0.5Hp pump at a flow rate of 20litres per minute through a 12 mm diameter polyvinyl chloride pipe. This process was controlled by a manual control valve. The surge tank was placed at a height of 1.75m from the ground and the water flowed by gravity through the aerator with a velocity of 0.156m/s, and a head loss of 0.09m to the filtration tank.

For flocculation to take place 50g of MO seed powder was added to the water in the tank and a hand stirrer was used to ensure good mixing. The suspension was subjected to 2 minutes of rapid mixing, followed by 5 minutes of slow mixing. Grey water was allowed to settle for 1 hour as recommended by Doerr (2005). The suspensions that were formed were removed manually after the settling period.

After the filtration process the grey water was subjected to an ultraviolet lamp. Ultraviolet disinfection provides a barrier against pathogens. Finally, chlorine (CL) residual was added to the recycled water to treat it and remove bad odour while in storage.

Thus the various processes that were followed-individually and in various combinations (Figure 4.13) include; Aerobic Screening (AS), Multimedia Filtration (MMF), Ultraviolet rays (UV) and Chlorination (CL). The quality of the treated grey water in terms of turbidity, pH, macro-pollutants nutrients, volatile fatty acids, trace elements, metals, chloride, nitrite and nitrate concentrations was tested after the treatment process has been completed.

A schematic illustration of the process that was followed for the grey water quality appraisal, appraisals of grey water resource content and impurities, and the treatment process up to recovery of resource content is presented in figure 4.13.

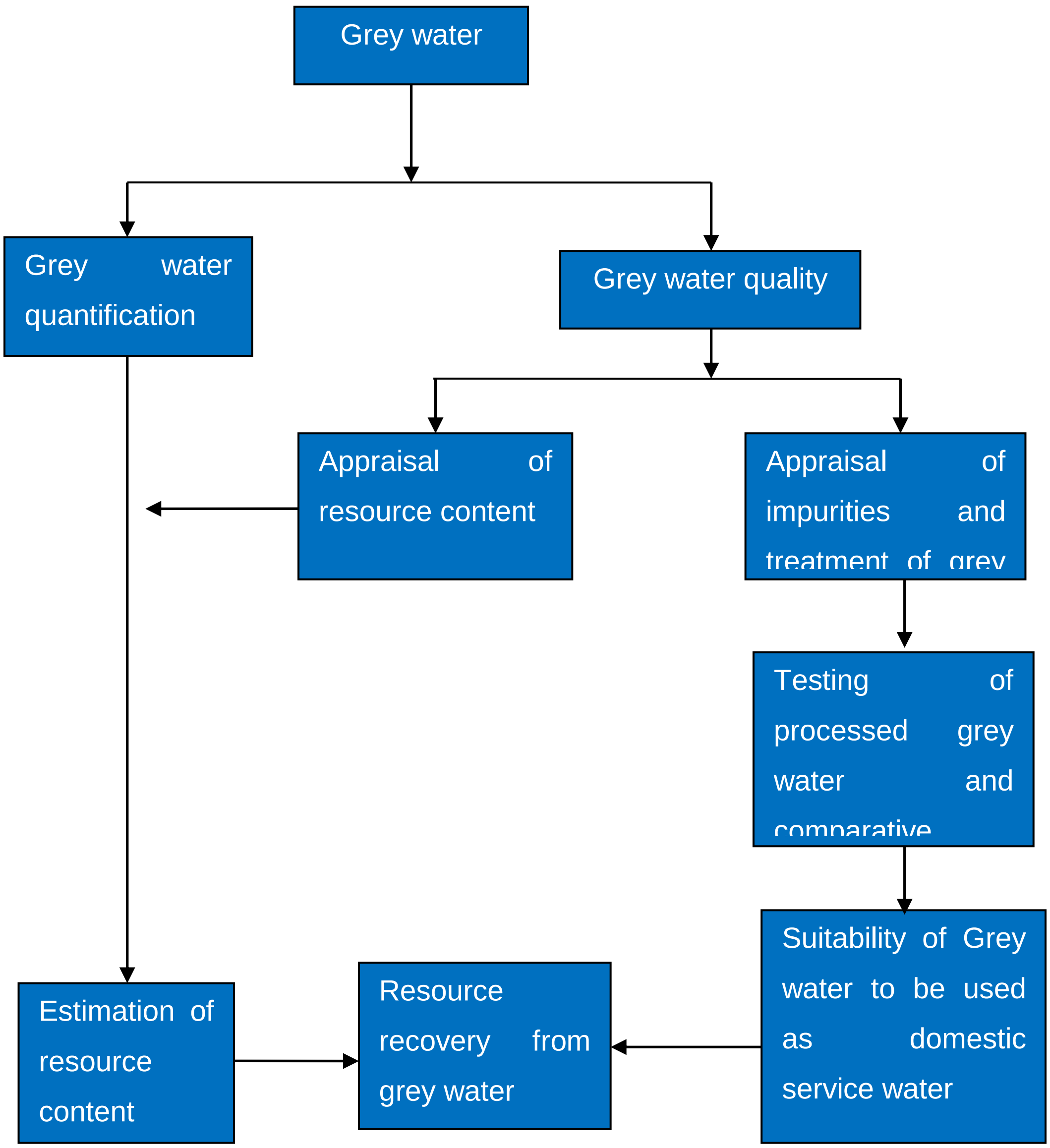

Figure 4.13: Grey water quality appraisal and quantification

4.7.2 Measuring pH of grey water

a) Definition of pH

The pH of a solution is the negative logarithm to the base ten of the hydrogen ion concentration, given by the expression: pH = $-\log_{10} [H^+]$ where $[H^+]$ is the hydrogen ion concentration. Water is acidic when its PH level is less than 7, and alkaline when its PH is level is higher than 7.

The pH of natural waters is the result of complex acid-base equilibria of various dissolved compounds, mainly the carbon dioxide-bicarbonate-carbonate equilibrium system, which is also affected by temperature. Conditions which favour production of hydrogen ions result in the lowering of pH and is referred to as an acidification process. Conversely, conditions which favour neutralisation of hydrogen ions result in an increase in pH, referred to as an alkalinisation process.

The pH of water does not indicate the ability to neutralise additions of acids or bases without appreciable change. This characteristic, termed buffering capacity, is controlled by the amounts of acidity and alkalinity present in water. Except at extremes, the pH of water does not have direct health consequences. The adverse effects of pH result from the solubilisation of toxic heavy metals and the protonation or deprotonation of other ions. The pH of the most of the raw water sources lies within the range of 6.5 - 8.5.

b) Importance and implication of pH

The main significance of pH in domestic water supplies relates to its effects on water treatment processes. The pH of water can be adjusted up or down by the addition of an alkali or an acid.

The selection of raw water as a domestic service source is never based solely on pH level. Danger to health would result primarily from the presence of metal ions, which are more likely to influence selection than the pH value. A direct correlation between the pH of drinking water and effects on human health is difficult, if not impossible to establish since pH is very closely associated with other aspects of water quality.

The taste of water, its corrosivity and the solubility and speciation of metal ions are all influenced by pH. At low pH water may taste sour, while at high pH water tastes bitter or soapy. The potential toxicity of metal ions and chemicals which can be protonated, for example ammonia, is influenced by pH. Changes in pH affect the degree of dissociation of weak acids and bases. This effect is of special importance because the toxicity of many compounds is affected by their degree of dissociation.

Corrosion in the water supply system is a major source of metal contamination in drinking water. Metals that have the potential for causing such contamination are lead, copper and zinc. Lead is subject to corrosion at a pH higher than 12. Corrosion of cadmium is only significant at pH below 6. Other metals which are frequently used in household plumbing and that may be affected by pH are copper and zinc.

c) Apparatus

A PH meter, conductivity meter and a glass beaker (Illustrated in Figure 4.14) were used in the study. The pH meter was used to measure the pH of the grey water samples while the conductivity meter was used to measure the extent of conductivity of the grey water.

Figure 4. 14: PH meter and conductivity meter and glass beaker

d) Procedure

The pH of grey water samples was measured electrometrically using a pH meter. The pH meter was calibrated against standard buffer solutions of known pH prior to measurement of a sample and fresh samples were used for determining the pH. The temperature at which measurements are made should always be reported, since pH measurement is influenced by temperature. Errors may be caused by the presence of sodium at pH values greater than 10. Measurements for pH in this study were performed at room temperature.

4.7.3 Measuring turbidity of grey water

a) Definition of turbidity

Turbidity is a measure of the light-scattering ability of water and is indicative of the concentration of suspended matter in water. The turbidity of water is also related to clarity, a measure of the transparency of water-and to settleable material, which refers to suspended matter which settles after a defined time period as opposed to that which remains in suspension. Thus turbidity affects the aesthetic quality of water.

Micro-organisms are often associated with turbidity, hence low turbidity minimises the potential for transmission of infectious diseases. The probability of the presence of carcinogenic asbestos fibres is also reduced under conditions of low turbidity.

b) Importance and implications of turbidity

Along an increase in turbidity, the amount of chlorine required for disinfection of the water increases. Low turbidity therefore minimises the chlorine dose required and reduces the formation of chloro-organics that often give rise to taste and odour problems as well as trihalomethanes. Due to the many advantages associated with water of low turbidity and the relative ease of monitoring turbidity, it is often used as an indicator of potential water quality problems during treatment.

Turbidity is strongly associated with apparent water colour**.** Although the correlation between turbidity, taste and odour of raw and treated water has long been recognised, all these constituents may also be present in the absence of excessive turbidity.

The consumption of turbid water *per se* does not have any direct health effects, but associated effects due to microbial contamination or the ingestion of substances bound to particulate matter, do have health effects. Turbidity can have a significant effect on the microbiological quality of water. Microbial growth in water is most extensive on the surface of particulates and inside loose, naturally-occurring flocs. River silt also readily adsorbs viruses and bacteria. During treatment, micro-organisms become entrapped in the floc formed during coagulation and breakthrough of the floc may represent significant microbial contamination.

Consumption of highly turbid, chlorinated water may therefore pose a health risk. Particulate matter can also protect bacteria and viruses against disinfection. The adsorptive properties of some suspended particles can lead to the entrapment of undesirable inorganic and organic compounds in water, including metal-humate complexes and herbicides (e.g. 2,4-D, Paraquat, Diquat). This may interfere with the detection of such compounds, and could be an indirect health risk. Turbidity may also be associated with the presence of inorganic ions such as manganese (II). For example, when water containing manganese(II) ions is treated with chlorine and left to stand, slow reaction kinetics indicate that colloidal manganese (IV) oxide is formed, leading eventually to the formation of a fine precipitate.

c) Apparatus

A turbidity meter (illustrated in Figure 4.15) was used to measure the degree of cloudiness of grey water due to the presence of murky particles. The turbidity meter has 3 empty glass vials to perform measurements in NTU, 4 standards for calibration and lubrication for the glasses.

Figure 4. 15: A Turbidity meter for measuring the degree of cloudiness of grey water

d) Procedure

The criteria refer to turbidity measured in nephelometric turbidity units (NTU). A nephelometric turbidimeter was used for the measurement of turbidity of grey water. Turbidity was determined on the day of sample collection. Due to irreversible changes in turbidity that could occur, samples were stored in the dark and for not more than 24 hours. Samples were shaken vigorously before examination.

4.7.4 Measuring total suspended solids in grey water

a) Definition

Suspended solids are the matter retained on a glass fibre filter after filtration of a well-mixed sample and drying of the filter at 103 - 105 EC. The settleable solids fraction is a component of the suspended solids fraction and is that fraction which settles out of solution within a defined period.

Suspended solids in water consist of inorganic and organic matter, such as clay, particles or suspended mineral matter, and a combination of decay products and living organisms respectively. In clear non-turbid waters, like spring water, the amount of suspended matter is low or absent, while in muddy waters the amount of suspended matter is high.

The amount of suspended matter found in the rivers draining a catchment area usually reflects the degree of soil erosion. Activities which result in accelerated soil erosion will therefore increase the suspended matter load in the draining rivers.

The settleable fraction of the suspended solids accumulates as sediment in lakes, dams and rivers. Scouring action during high flow periods in rivers can resuspend settled matter and finer particles can remain in suspension for long periods.

b) Importance and implications of total suspended solids

Suspended solids give rise to turbidity in water. The correlation between the amount of suspended solids and turbidity measurement is, however, dependent on the nature and particle size distribution of the suspended matter. Addition of strongly electropositive ions such as Fe(III) and Al(III) salts to water will neutralise the electrical repulsive charges on the suspended matter and allow coagulation and settling to occur.

The presence of suspended solids in water supplies is one of the main causes of fouling. Fouling is the accumulation of inorganic and organic solid matter, other than scale, and it interferes with the normal operation of a facility and may contribute to its deterioration. Fouling is generally encountered in steam generation and cooling water systems, where it causes blockages, impedes air circulation and can lead to localised overheating in boilers with subsequent metal damage. It is also one of the chief causes of foaming and priming in boilers.

Suspended solids may be abrasive and cause failure of pump seals, bearings or valves and controls. Suspended solids promote microbial growth and the consequent buildup of slime which acts as a sediment trap. Such microbial slimes often contain sulphate-reducing bacteria (SRB) responsible for microbially-influenced / induced corrosion (MIC), which results in serious damage to pipelines and equipment. In paper making, suspended solids can cause blockages of fine spray nozzles and edge cutters of paper machines, as well as the clogging of wire screens. Suspended solids foul ion exchange resins, reducing their life span and increasing the cost of regeneration.

Suspended solids interfere with the finish of paper products by dulling the brightness of colours and affecting the texture and uniformity of the products. Suspended solids can interfere with oxidising bleaches by creating an additional oxygen demand- and thus adversely affect the brightness of bleached fibres. Colours are dulled and suspended solids may also leave marks on the cloth. In bottling of carbonated drinks, small quantities of suspended solids may cause foaming, poor carbonation and other bottling problems.

c) Apparatus and procedure

The criteria for the suspended solids concentration are given in units of mg/R. Suspended solids in grey water were measured as the mass of material retained on a glass fibre filter after drying at 103 - 105 EC. Settleable solids were determined by difference after a one-hour settling period followed by determination of the suspended solids in the supernatant.

4.7.5 Measuring Chemical Oxygen Demand (COD) of grey water

a) Definition

Chemical Oxygen Demand (COD) is defined as the measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant. Most organic compounds can be oxidised to between 95 % - 100 % of their theoretical value. The COD therefore gives an estimate of the organic matter present in a water body.

b) Importance and implications

Organic matter adhering to or absorbed by mucilaginous biofilms augments material fouling in heat exchanger and cooling systems. It also promotes the formation of microbial slimes, acting as a nutrient source for bacterial growth. Such microbial slimes often contain sulphate-reducing bacteria (SRB), which are responsible for extensive damage to heat exchange and cooling systems through microbially-influenced / induced corrosion (MIC).

Organic matter can also foul ion exchange resins and electro-dialysis as well as put pressure on membrane processes, thereby curtailing operational cycles before regeneration, and causing loss of exchange capacity due to irreversible exchanges. Products of degraded organic compounds passing through ion exchange beds can cause problems in steam generation systems by promoting corrosion/erosion in steam and condensate return lines.

Some organic acids of human origin - or soil-derived material interfere with the colour of dyes used in the finishes of leather and in the production of paper and textiles. The additional oxygen demand exerted by excessive organic matter in oxidative bleaching operations and cooling systems leads to the use of surplus bleaching agent or increased quantities of oxidising biocides respectively.

c) Reagents and materials

- Ultra-pure water
- Hach COD reagent vials high range (20-1500mg/L COD) and low range (3-150mg/L COD).
- 1000mg/L COD standard
- 50mg/L COD standard (purchased)
- KHP salt
- 300mg/L COD Quality Control standard for High Range.
- 10mg/L COD Quality Control standard for Low Range

d) Apparatus and equipment

- DR3900 Spectrophotometer
- DRB200 Reactor that heats to 150ºC
- 1 – 10ml Dedicated automated pipette
- Vials steel racks
- 10ml Pipette tips
- 100ml Volumetric flask

e) Procedure

Chemical Oxygen Demand is defined as the amount of a specified oxidant that reacts with the sample under controlled conditions. Most types of organic matter are oxidized by a boiling mixture of chromic and sulphuric acids. Potassium dichromate is a strong oxidizing agent under acidic conditions. (Acidity is usually achieved by the addition of sulphuric acid).

In the process of oxidizing the organic substances found in the water sample, potassium dichromate is reduced (since in all redox reactions, one reagent is oxidized and the other is reduced), forming Cr3+. The amount of Cr3+ is determined after oxidization is complete, and is used as an indirect measure of the organic contents of the water sample.

4.7.6 Measuring dissolve iron in grey water

a) Definition

Pure iron is silvery in colour but usually appears as greyish black or brown deposits as a result of oxidation. Iron is found in three oxidation states, namely, 0, II and III of which the III oxidation state is the most common. In water, iron can be present as dissolved ferric iron, Fe(III), as ferrous iron, Fe(II) or as suspended iron hydroxides. Biologically iron is an essential micronutrient required by all living organisms. High concentrations of iron are predominantly an aesthetic concern since ferrous salts are unstable under the pH conditions prevailing in drinking water and precipitate as insoluble ferric hydroxide, which settles out as a rust-coloured silt.

The concentration of dissolved iron in water is dependent on the pH, redox potential, turbidity, suspended matter, the concentration of aluminium and the occurrence of several heavy metals, notably manganese. The natural cycling of iron may also result in the presence of trace metals such as arsenic, copper, cadmium and lead.

b) Importance and implications

Iron is the fourth most abundant element and constitutes five percent of the earth's crust. It is found in many minerals, the most common of which is haematite (Fe_2O_3), widely used as an iron ore for metallurgical purposes. Other important iron minerals are pyrite (FeS_2), 2 siderite ($FeCO_3$), magnetite ($Fe_3 O_4$), goethite ($Fe_2 O_3 .H_2O$) and limonite ($2Fe_2 O_3 .3H_2 O$), as well as a number of mixed ores, such as chalcopyrite ($CuFeS_2$) and arsenopyrite (FeAsS). Pyrite is often associated with coal formations and iron may occasionally also be found in the elemental form, either as terrestrial iron or as meteoric iron. The reddish colour of soil is due to iron, the median concentration thereof in soil being 4.0 % (m/m). Typically, the concentration of dissolved iron in: unpolluted surface water is in the range of 0.001 - 0.5 mg/L; and sea water, is approximately 0.002

mg/L. The speciation of iron is strongly related to the pH and the redox potential of the water. At neutral or alkaline pH, under oxidising conditions, the dissolved iron concentration is usually in the µg/L range but under reducing conditions, soluble ferrous iron may be formed and substantially higher concentrations in the mg/L range may be encountered. Where marked acidification of the water occurs and the pH is less than 3.5, the dissolved iron concentration can be several hundred mg/L, as may be the case with acid mine drainage.

Excessive ingestion of iron may result in haemochromatosis; wherein tissue damage occurs as a consequence of iron accumulation. Haemochromatosis generally results from prolonged consumption of acid foodstuffs cooked in kitchenware made of iron. Poisoning is rare since excessively high concentrations of iron do not occur naturally in water. The extreme unpalatability of such water would probably prevent consumption. Further, iron in the distribution system promotes proliferation of iron-oxidising bacteria which oxidise ferrous iron to ferric iron, and manifest as slimy coatings in plumbing when the iron concentration of the water in the distribution system approaches 0.3 mg/l. Effects are predominantly aesthetic, such as the staining of enamelled surfaces of baths, hand basins and lavatory cisterns/bowls and laundry. Iron causes discolouration of water supplies when present at low concentrations in association with aluminium. Iron that settles out in distribution systems gradually reduces the flow rate of water. The only associated health effects are those that could arise from the presence of microbial deposits on internal surfaces of plumbing.

c) Apparatus and Procedure

The criteria are given in terms of the total iron concentration, expressed in units of mg/L.

The reference method for the determination of iron was by atomic absorption spectrometry (AAS), using an air-acetylene flame. Measurement of the total iron concentration required acidification followed by filtration prior to AAS analysis. Where other methods were used, their characteristics relative to the reference method were recognised.

4.7.6 Measuring manganese in grey water

a) Definition

Manganese is a grey-white brittle metal and is found in several oxidation states, namely -III, -I, 0, I, II, III, IV, V, VI and VII. It is an essential element for humans and animals, but is neurotoxic in excessive amounts. At concentrations usually encountered in water, manganese has aesthetic, rather than toxic effects.

b) Importance and implications

Adverse aesthetic effects limit the acceptability of manganese-containing water for domestic use at concentrations exceeding 0.15 mg/R. An unpleasant taste is imparted to beverages, and staining of plumbing fixtures and laundry occurs. Oxidation of manganous Mn(II) compounds in solution results in precipitation of hydrated manganese(IV) oxide/hydroxide causing encrustation in plumbing fixtures.

Uptake of manganese occurs by ingestion from both food and water, but more so from food. Manganese exhibits a low solubility in gastric fluids; only three to four percent of ingested manganese is absorbed from the gastrointestinal tract. Manganese in the body is regulated primarily by excretion through the pancreas, although excretion directly through the gut wall and in the urine also takes place.

It has been suggested that the presence of manganese in drinking water may be inversely related to cardiovascular mortality. Deficiencies result in anaemia, growth impairment and skeletal abnormalities. The absorption of manganese in the digestive tract is closely linked to the absorption of iron. Manganese absorption is also inversely related to the level of calcium in the diet and directly related to the level of potassium

.

Neurotoxic effects may occur at high concentrations, but manganese is considered to be one of the least potentially harmful of the elements. Only extreme exposure to manganese, such as may occur from industrial exposure, is likely to lead to manganese poisoning. A causative link between manganese ingestion and Parkinson's disease has been tentatively suggested but not confirmed.

Manganese supports the growth of certain nuisance organisms in water distribution systems, giving rise to taste, odour and turbidity problems.

c) Apparatus and procedure

Manganese is measured as total manganese, in units of mg/L. The reference method for the determination of manganese in water is atomic absorption spectrometry, using an airacetylene flame. Samples should be acidified prior to analysis to dissolve manganese adsorbed to suspended matter.

The aquatic chemistry of manganese is closely associated with that of **iron** chemistry. Both elements tend to behave synergistically in their dissolution from sediments under anaerobic conditions and reprecipitate under aerobic conditions. Manganese, once in solution, is more readily stabilised by complexation than iron is, and is often difficult to remove from solution except at high pH, where it precipitates as the hydroxide. Like iron, manganese can be utilised by metallophilic bacteria.

Other water constituents and properties that govern the action of manganese in water are pH, redox potential, turbidity, suspended matter and the concentration of aluminium.

4.7.7 Measuring dissolve aluminium in grey water

a) Definition

Pure aluminium is a silvery-white, soft, light metal that is resistant to corrosion by the formation of a thin protective layer of the oxide of aluminium. Aluminium does not appear to be an essential nutrient for humans and is for all practical purposes non-toxic at near-neutral pH values in unpolluted environments. Aluminium salts are not normally absorbed from food and water, but are complex with phosphate and are excreted in the faeces. The dietary intake of aluminium can be as much as 10 mg/day.

b) Importance and implications

Aluminium is the most common metal in the earth's crust, having an abundance of 81 g/kg. Aluminium does not occur in the elemental form, but its minerals- particularly the silicates of aluminium - are widespread. Some important minerals containing aluminium are bauxite (hydrated aluminium oxide), spinel (magnesium aluminium oxide) and the kaolins (various aluminium silicates)

The main effects of aluminium in domestic water are aesthetic, relating to discolouration in the presence of iron or manganese. Aluminium is also used in water treatment processes, which may result in increased concentrations of aluminium in the final water. Prolonged exposure to aluminium has been implicated in chronic neurological disorders such as dialysis dementia and Alzheimer's disease. It is, however, not clear whether the presence of aluminium causes such conditions or is an indicator of other factors. Therefore, the link between aluminium in water and adverse effects on human health remains to be conclusively identified. Although not strictly related to consumption of drinking water, the consumption of large quantities of aluminium hydroxide in the form of proprietary "antacids" for the relief of minor stomach discomforts can lead to excessive loss of phosphate.

c) Apparatus and procedure

The criteria refer to the dissolved aluminium concentration, i.e. aluminium which passes through a 0.45 µm membrane filter. The reference method for determining the concentration of aluminium was atomic absorption spectrometry using a nitrous oxide flame and addition of potassium as an ionisation suppressant.

If total aluminium (the dissolved plus suspended fraction) was measured, the sample was acidified before filtration. A vigorous digestion step was done since the acidification step only dissolves types such as aluminium hydroxide and not aluminium silicate minerals.

4.7.8 Measuring alkalinity of grey water

a) Definition

Alkalinity is the measure of the acid-neutralising capacity of water and as such, it is also an indication of the base content. Ions which commonly contribute to the alkalinity of water are bicarbonate (HCO_3) and carbonate (CO_3^{-2}), and at high pH values, hydroxide (OH^-). The total alkalinity is the sum of these three ions. Other ions which can also contribute to the alkalinity are borates, silicates, phosphates and some organic substances.

b) Importance and implications

Scaling is chiefly the deposition of insoluble calcium carbonate and is a major problem wherever heating of water or heat exchange takes place. Elevated concentrations of alkalinity and hardness are conducive to scaling. Scale accumulates on heat exchange surfaces, insulating them, and reducing heat exchange efficiency. Scaling of internal passageways of heat exchangers and pipelines decreases working volume and restricts flow. Scaling may also lead to problems in other items of industrial equipment, such as screens, vacuum pumps, heating baths, steam-heated drying drums and tanks. Scale can also form on paper machine wires and felts, necessitating special cleaning procedures that can reduce their active life.

Uneven distribution of scale in boilers can lead to localised overheating with subsequent boiler failure due to distortion and fatigue. High alkalinity in boiler feed water may affect surface tension properties promoting foaming and the carryover of undesirable dissolved salts with the steam. Excessive bicarbonates and carbonates in boiler water give rise to carbon dioxide in the steam, which promotes corrosion in condensate and steam pipelines. Low alkalinity water may also be undesirable, since the lack of pH buffering capacity associated with low alkalinity may be conducive to corrosion. A certain degree of alkalinity may act as a corrosion inhibitor.

c) Apparatus and procedure

The criteria are presented in terms of the total alkalinity concentration, expressed as mg $CaCO_3^{/-}$

The reference method for the determination of total alkalinity was by titration of the sample with a strong acid (usually hydrochloric acid), of known concentration, to the methyl orange end-point. Other methods of determining the total alkalinity, such as potentiometric titration and titration using a suitable mixed indicator were also acceptable in the study.

4.7.9 Measuring calcium in grey water

a) Definition

Calcium is an alkaline earth metal and exists as the doubly positively-charged ion, Ca(II). Calcium occurs naturally in varying concentrations in most waters and, together with magnesium, is one of the main components of water hardness. Soft waters contain low, while *hard* waters contain high concentrations of calcium. Calcium is an essential element for all living organisms and is an important constituent of the bony skeleton of mammals, which consists of phosphates of calcium.

b) Importance and implications

Calcium is an important mineral element in the human diet, the total daily dietary intake being in the range of 500 - 1 400 mg/day. Calcium has been reported as exerting a protective action against cardiovascular disease. However, the available data purporting to show an inverse relationship between hardness or the calcium concentration of water, and the occurrence of cardiovascular disease do not demonstrate an unequivocal causal relationship. There is no conclusive evidence to support claims for the increased incidence of human kidney and urinary tract stones (urolithiasis) resulting from the long-term consumption of water with high concentrations of calcium. Calcium is known to mitigate the toxicity of certain heavy metals.

Scaling, the principal undesirable effect which occurs in water heating appliances such as kettles, urns, geysers, boilers and certain pipes, results in less efficient use of electrical power and any other fuel used for heating purposes, and the partial obstruction of pipes. High concentrations of calcium impair the lathering of soap by the formation of insoluble calcium salts of long chain fatty acids that precipitate as scums. This results in excessive soap consumption in personal hygiene and, in rare cases- in household cleaning operations. In addition, the scums are anaesthetic, leading in the long-term to the marking of enamelled surfaces such as baths and hand basins.

c) Apparatus and procedure

The criteria refer to the dissolved calcium concentration, measured in units of mg (Ca). The reference method for the determination of calcium was atomic absorption spectrometry, using a phosphate interference inhibitor such as lanthanum, and an ionisation suppressant, such as caesium or potassium.

4.7.10 Measuring chloride in grey water

a) Definition

Chloride is the anion of the element chlorine. Chorine does not occur in nature, but is found only as chloride. The chlorides of sodium, potassium, calcium and magnesium are all highly soluble in water.

Chloride is of concern in domestic water supplies because elevated concentrations impart a salty taste to water and accelerate the corrosion rate of metals. High concentrations of chloride can also be detrimental to chloride-sensitive garden plants.

Chloride is a highly soluble common constituent in water, and once in solution it tends to accumulate. Typically, concentrations of chloride in fresh water range from a few to several hundred mg/L. In sea water the concentration is approximately 19 800 mg/L. Chloride inputs to surface waters can arise from irrigation return flows, sewage effluent discharges and various industrial processes. Chloride can only be removed from water by energy-intensive processes or ion exchange.

b) Importance and implications

Chloride is only detectable by taste at concentrations exceeding approximately 200 mg/R. A salty taste becomes quite distinctive at 400 mg/L and objectionable at greater than 600 mg/L.

At chloride concentrations greater than 2 000 mg/L nausea may occur, while at 10 000 mg/L vomiting and dehydration may be induced.

Chloride accelerates the corrosion rate of iron and certain other metals well below the concentration at which it is detectable by taste. The threshold for an increased corrosion rate is approximately 50 mg/L. At chloride concentrations greater than 200 mg/L, there is likely to be a significant shortening of the lifetime of domestic appliances as a result of corrosion.

c) Apparatus and procedure

The criteria are given in terms of the dissolved chloride concentration, in units of mg/L. The reference method used for the determination of dissolved chloride was colorimetry, with ferricyanide.

4.7.11 Measuring potassium in grey water

a) Definition

Potassium is an alkali metal which reacts violently with water to form positively-charged potassium ions. Potassium always occurs in water in association with anions, usually chloride- but can also occur with sulphate, bicarbonate - or nitrate. Potassium is the main intracellular cation in living organisms and is an essential dietary element.

Potassium is ubiquitous in the environment. Common potassium-containing minerals are the feldspars and micas, and potassium is also found in association with sodium in many minerals. Potassium salts are highly soluble in water and precipitation does not occur on evaporation until very high concentrations are reached and potassium therefore has a strong tendency to remain in water. Since sodium salts are generally cheaper than the corresponding potassium salts, industries predominantly use sodium rather than potassium salts. Therefore, sodium is usually found at higher concentrations than potassium in wastes and brines.

b) Importance and implication

Potassium is an important intracellular cation and the total dietary intake ranges from 1.6 - 4.7 g/day, depending on age. At high concentrations potassium imparts a bitter taste to water, and consumption can induce nausea and vomiting. Consequently, excessive concentrations of potassium salts ingested orally are relatively harmless to healthy adults, since the protective vomiting reflex rids the system of dangerous excesses. Healthy humans are relatively insensitive to any harmful effects caused by potassium, but electrolyte disturbances can occur, particularly in infants or in patients with kidney pathologies who are on a potassium-restricted diet

Apparatus and procedure

The criteria are given in terms of the dissolved potassium concentration, in units of mg/R. The reference method used for the determination of dissolved potassium was by flame photometry, using lithium as an internal standard.

4.7.12 Measuring sulphates in grey water

a) Definition

Sulphate is the oxy-anion of sulphur in the +VI oxidation state and forms salts with various cations such as potassium, sodium, calcium, magnesium, barium, lead and ammonium. Potassium, sodium, magnesium and ammonium sulphates are highly soluble. Whereas calcium sulphate is partially soluble, barium- and lead sulphates are insoluble. Consumption of excessive amounts of sulphate in drinking water typically results in diarrhoea. Sulphate imparts a bitter or salty taste to water, and is associated with varying degrees of unpalatability.

Sulphate is a common constituent of water and arises from the dissolution of mineral sulphates in soil and rock, particularly calcium sulphate (gypsum) and other partially soluble sulphate minerals. Since most sulphates are soluble in water, and calcium sulphate relatively soluble, sulphates tend to accumulate to progressively increasing concentrations when added to water.

Sulphates are discharged from acid mine wastes and many other industrial processes such as tanneries, textile mills and processes using sulphuric acid or sulphates. Sulphates can be removed or added to water by ion exchange processes, and microbiological reduction or oxidation can interconvert sulphur and sulphate. The microbiological processes tend to be slow and require anaerobic conditions usually only found in sediments and soils. Atmospheric sulphur dioxide, discharged on combustion of fossil fuels, can give rise to sulphuric acid in rainwater (acid-rain) and as such, this results in the return of sulphate to surface waters in the environment.

b) Importance and implications

High concentrations of sulphate exert predominantly acute health effects (diarrhoea). These are temporary and reversible since sulphate is rapidly excreted in the urine. Individuals exposed to elevated sulphate concentrations in their drinking water for long periods, usually become adapted and cease to experience these effects. Sulphate concentrations of 600 mg/L and more cause diarrhoea in most individuals and adaptation may not occur.

Sulphate imparts a salty or bitter taste to water. The taste threshold for sulphate falls in the range of 200 - 400 mg/L and depends on whether the sulphate is predominantly associated with sodium, potassium, calcium or magnesium, or mixtures thereof. Elevated sulphate concentrations also increase the erosion rate of metal fittings in distribution systems.

4.7.13 Measuring sodium in grey water

a) Definition

Sodium is an alkali metal which reacts with water to form highly soluble, positively-charged sodium ions. It is an essential dietary element important for the electrolyte balance and the maintenance of many essential physiological functions. Sodium is present in all food to varying degrees.

Sodium is ubiquitous in the environment and usually occurs as sodium chloride, but sometimes as sodium sulphate, bicarbonate or even nitrate. Sodium is found as solid sodium chloride (rock salt) in areas where geological deposits occur. The levels of sodium in surface waters are generally low in areas of high rainfall and high in arid areas with low mean annual precipitation. Sodium is highly soluble in water and does not precipitate when water evaporates, unless saturation occurs. Hence, water in arid areas often contains elevated concentrations of sodium. High concentrations also occur in sea water, at approximately 11 g/L.

b) Importance and implications

The taste threshold for sodium in water varies from 135 - 200 mg/L, depending on the associated anion. The common ones include chloride, sulphate, nitrate, bicarbonate and carbonate. Sodium intake can exacerbate certain disease conditions. Persons suffering from hypertension, cardiovascular or renal diseases should restrict their sodium intake. In the case of bottle-fed infants, sodium intake should also be restricted.

c) Apparatus and procedure

The criteria are given in terms of the dissolved sodium concentration, in units of mg/L. For all practical purposes this was identical to the total sodium concentration, as sodium is always in the dissolved form, except in supersaturated brines. The reference method used for the determination of sodium was flame photometry, with lithium as the internal standard.

4.7.14 Measuring nitrate/nitrite in grey water

a) Definition

Nitrate is the end product of the oxidation of ammonia or nitrite. Nitrate (NO_3^-) and nitrite (NO_2^-) are the oxyanions of nitrogen in which nitrogen is found in the +V and +III oxidation states, respectively. Nitrates and nitrites occur together in the environment and interconversion readily occurs. Under oxidising conditions nitrite is converted to nitrate, which is the most stable positive oxidation state of nitrogen and far more common in the aquatic environment than nitrite. Nitrate in drinking water is primarily a health concern in that it can be readily converted in the gastrointestinal tract to nitrite as a result of bacterial reduction.

b) Importance and implications

Upon absorption, nitrite combines with the oxygen-carrying red blood pigment, haemoglobin, to form methaemoglobin, which is incapable of carrying oxygen. This condition is termed methaemoglobinaemia. The reaction of nitrite with haemoglobin can be particularly hazardous in infants under three months of age and is compounded when the intake of Vitamin C is inadequate. Metabolically, nitrates may react with secondary and tertiary amines and amides, commonly derived from food, to form nitrosamines which are known carcinogens.

Nitrate tends to increase in shallow ground water sources in association with agricultural and urban runoff, especially in densely populated areas. Nitrate together with phosphates stimulate plant growth. In aquatic systems elevated concentrations generally give rise to the accelerated growth of algae and the occurrence of algal blooms. Algal blooms may subsequently cause problems associated with malodours and tastes in water and the possible occurrence of toxicity.

c) Apparatus and procedure

The criteria for nitrate are given in terms of the concentration of nitrate plus nitrite nitrogen in units of mg/L. The reference method used for the determination of the sum of the nitrate and nitrite concentration was through cadmium reduction followed by diazotisation. Nitrite alone can be determined by diazotisation without prior reduction of the nitrate.

4.7.15 Measuring ammonia in grey water

a) Definition

Ammonia (NH_3), where the nitrogen atom is in the III oxidation state, can readily take up an additional hydrogen ion to form the ammonium ion NH_4^+. In solution ammonia occurs in equilibrium with the ammonium ion and the position of equilibrium is governed by pH and temperature.

At high pH, ammonia exits predominantly as a gas in solution, and can be released to the atmosphere from water. At low and neutral pH, ammonia is found predominantly as the ammonium ion. Ammonia can also be microbiologically oxidised to nitrates.

b) Importance and implications

At Ammonia is not toxic to man at the concentrations likely to be found in drinking water but does exert other effects. For example, elevated concentrations of ammonia can compromise the disinfection of water and give rise to nitrite formation in distribution systems, which may result in taste and odour problems.

The chemistry of ammonia is very complex, especially where transition metals are present in water, and while ammonia itself is of relatively low toxicity, this is not necessarily the case for some of its organometallic complexes. For example, elevated concentration of ammonia can compromise the disinfection of water and give rise to nitrite formation in distribution systems, which may result in taste and odour problems.

Taste and odour complaints are likely to occur if the ammonia concentration exceeds, 1.5 mg/L. Nitrite, is also potentially toxic, especially to infants.

c) Apparatus and procedure

The criterion was based on the free ammonia nitrogen concentration. Which is the sum of the NH_3 and NH_4 nitrogen concentrations, and it is presented in units of mg/L? The reference method used for the determination of ammonia was the phenate colorimetric method, where an intensely blue compound, indophenol, is formed from the reaction of ammonia, phenol, and hypochlorite, under catalysis by Mn(II).

4.7.16 Measuring heterotrophic bacteria in grey water

a) Definition

Heterotrophic bacterial counts are used to indicate the general microbial quality of water.

They are also used to assess the efficiency of water treatment and disinfection processes, to test the integrity of distribution systems for after-growth and to determine the quality of water used in industrial processes.

Heterotrophic plate counts do not indicate possible faecal pollution nor do they represent the total number of bacteria present in the water. Only those bacteria able to grow under the specific conditions of the test are counted. Various methods and media exist to perform this analysis and it is also referred to as a standard plate count or colony count.

Heterotrophic plate counts detect a wide range of bacteria which are omnipresent in nature. Pollution of water can give rise to conditions conducive to bacterial growth, such as high nutrient concentrations and high turbidity and can result in a substantial increase of these naturally-occurring organisms.

b) Importance and implication

Heterotrophic plate counts are used to assess the general bacterial content of water but do not necessarily represent the total bacterial population present. High heterotrophic plate counts in treated water indicate inadequate treatment of the water, post-treatment contamination or bacterial after-growth in the distribution system. Therefore, pathogenic micro-organisms, bacteria, viruses or parasites could possibly be present in the water and pose a health risk when the water is used for domestic consumption.

c) Apparatus and procedure

Heterotrophic plate counts are usually reported as counts (number of colonies)/ml. Three alternative methods for determining the heterotrophic plate count in a water sample have been approved by the American Standard Methods Committee, namely pour plates, spread plates and membrane filtration methods. Various media are used which could result in variation in the results. The filtration method was used in this study. Results were obtained after incubation at 35EC for 48 hours- as this temperature and period of incubation favours the detection of faecal organisms.

4.7.17 Measuring total coliform in grey water

a) Definition

Total coliform bacteria counts are frequently used to assess the general hygienic quality of water and to evaluate the efficiency of drinking water treatment and the integrity of the distribution system. Coliform should not be detectable in treated water supplies. If present, this suggests inadequate treatment. In some instances, coliform may indicate the presence of pathogens responsible for the transmission of infectious diseases.

b) Importance and Implication

Total coliform counts are primarily used in the evaluation of water treatment processes.

They indicate microbial growth in the distribution system or post-treatment contamination of drinking water. The total coliform group includes bacteria of faecal origin and indicates the possible presence of bacterial pathogens such as Salmonella spp., Shigella spp., Vibrio cholerae, Campylobacter jejuni, C. coli, Yersinia enterocolitica and pathogenic E. coli, especially when detected in conjunction with other faecal coliforms. These organisms can cause diseases such as gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever.

c) Apparatus and procedures

Total coliforms are usually enumerated as counts (number of colonies)/100 ml. Samples were refrigerated immediately after collection and were analysed within six hours.

Prior to analysis, domestic water samples containing residual chlorine were dechlorinated, usually with sodium thiosulphate. Analysis may be by membrane filtration (0.45 Fm diameter pore size), pour plates or by multiple tube fermentation techniques. In this study the filtration method was applied to analyse total coliforms in grey water. The total coliform bacteria are all bacteria which produce colonies with a typical metallic sheen within 20 - 24 hours of incubation at 35 EC on m-Endo agar.

4.7.18 Measuring E-coli in grey water

a) Definition

Faecal coliforms, and more specifically *Escherichia coli (E. coli)*, are the most commonly used bacterial indicators of faecal pollution. This indicator group is used to evaluate the quality of wastewater effluents, river water, and sea water at bathing beaches, raw water for drinking water supply, treated drinking water, water used for irrigation and aquaculture and recreational waters. The presence of *Escherichia coli* is used to confirm the presence of faecal pollution by warm-blooded animals (often interpreted as human faecal pollution). Some organisms detected as faecal coliforms may not be of human faecal origin but are almost definitely from warm-blooded animals.

b) Importance and implications

Faecal coliforms are primarily used to indicate the presence of bacterial pathogens such as Salmonella spp., Shigella spp. Vibrio cholerae, Campylobacter jejuni, Campylobacter coli, Yersinia enterocolitica and pathogenic *E. coli*. These organisms can be transmitted via the faecal/oral route by contaminated or poorly-treated drinking water and may cause diseases such as gastroenteritis, salmonellosis, dysentery, cholera and typhoid fever. The risk of being infected by microbial pathogens correlates with the level of contamination of the water and the amount of contaminated water consumed. Higher concentrations of faecal coliforms in water will indicate a higher risk of contracting waterborne disease, even if small amounts of water are consumed.

c) Apparatus and procedure

Faecal coliforms are usually enumerated as counts (number of colonies)/100 ml of water.

Grey water samples were refrigerated immediately after collection and were analysed within six hours. Prior to analysis, grey water samples containing residual chlorine were dechlorinated, with sodium thiosulphate. Analysis may be by membrane filtration (0.45 Fm diameter pore size), pour plates or by multiple tube fermentation techniques. Faecal coliform bacteria are all bacteria which produce typical blue colonies on m-FC agar within 20 - 24 hours of incubation at 44.5 EC. *Escherichia coli* are considered to be all the faecal coliforms which test indole-positive at 44.5 EC. In this study filtration was used to analyse E-coli in grey water.

4.8 Data analysis

Data analysis was split into experimental and household survey data analysis. A detailed discussion of each analysis method that was used in the study follows below.

4.8.2 Experimental data analysis

Concentration of metals, pH, macro-pollutants (total, suspended and dissolved COD, TOC), nutrients, volatile fatty acids, trace elements, chloride, nitrite, nitrate, phosphorous and potassium were examined in treated and untreated samples. Descriptive statistical analysis such as mean, range, coefficient of variation and standard deviation were conducted to understand the variability of the quality of grey water. Comparative analysis of treated grey water with acceptable standard and untreated grey water was done using two sample t-tests to understand the serviceability of the processed grey water. Relations between BOD, COD, TSS and turbidity were also established using correlation analysis.

Grey water was treated in 8 simulated scenario combinations that were composed of AS + MMF, AS+UV, AS+CL, MMF+UV, MMF+CL, AS+ MMF+CL, AS+ MMF+UV and AS+ MMF+UV+CL. The purpose of this analysis was to compare the physical, chemical and operational characteristics of grey water after treatment under each combination illustrated above. This helped to identify a combination that is cost effective and could give best results in terms of grey water quality that meet expected standards for domestic service purposes.

4.8.3 Household data analysis

Frequencies and percentages were used to describe the distribution of participants across location within the city Witbank. Mean values were used to provide information on household water consumption, grey water production and income patterns across locations. However, inferential statistics was used to indicate correlation among variables. The association between income, water consumption and grey water production was discussed with reference to the Chi- Square and linear regression. The Chi- Square test provided significance, magnitude of the association as well as direction of the pairwise association between income and grey water, income and grey water production, and income and water consumption.

Correlation between water demand and income, and grey water production and income were discussed with reference to the linear regression. In the first case, water demand was the dependent variable while income was the independent variable. In the second instance, grey water production was the dependent variable while income was the independent variable.

Analysis of Variance and t-tests were used to compare income, water consumption and grey water production across Witbank locations (these included upscale development, city, townships and central areas). Analysis of Variance is a statistical procedure that is used to determine whether there are any significant differences between the means of three or more independent cohorts or groups of a population (in the case of this study, locations were considered as the cohorts). Analysis of Variance uses F test and p values to statistically test equality of means. P values of less than 0.05 means that significant differences in means exists among groups under investigation while the opposite hold true as well. On the other hand, T tests were used to determine whether there were any significant differences in means across two locations at a given time with regards to income, water consumption, grey water production and water usage per capita.

4.9 Conclusion

The chapter gave an outline of the research methodology being followed in this study from data collection up to analysis. An experimental study was performed to examine the quality (impurities and nutrient content) of grey water generated in the study area and to quantify the availability of different resources such as nitrogen, potassium and phosphorus which can be recovered from grey water. Grey water quality was processed under different simulated scenarios of individual and different combinations of treatment processes.

Survey questionnaires were also used to collect data related to income, water consumption, grey water production and water usage per capita in the household of each participant. The survey helped to understand average income levels, water consumption patterns, and grey water production and management of households within the study area. The next chapter shall focus on the presentation of results, and the discussion of findings.

CHAPTER 5: RESULTS, DISCUSSION AND FINDINGS

5.1 Introduction

Availability of quality water for domestic purposes is a challenge experienced all over the world including South Africa and the situation is estimated to worsen in the future if no effective solutions are provided. As a starting point, it has been observed that numerous cities around the world produce large amounts of grey water (waste water from kitchen, showers, laundry activities, and bath tubs) that can be recycled and re-used for domestic purposes. Recycling of grey water for domestic purposes can reduce the pressure on a country's water resource and it also presents the possibility of nutrients recovery such as Nitrogen, Phosphorous and Potassium to name a few.

Therefore, an empirical study was conducted in the South African city Witbank in the Mpumalanga Province to examine the quality (impurities and nutrient content) of grey water generated in the study area and to quantify the availability of various resources such as nitrogen, potassium and phosphorus, which can be recovered from grey water. This chapter provides detailed results, and discussions of findings of the study which form a basis for the last chapter that deals with recommendations and conclusions. The first part of this chapter analyses and discusses the household data collected from participants residing in Witbank. The second part of the analysis is based on the experimentation with treatments of grey water.

5.2 Household survey data analysis

A grey water survey in the form of a standardised questionnaire was conducted in a South African city Witbank. As grey water management is affected mostly by sociological, environmental and institutional factors, it necessitates the collection of data and the use of specialist knowledge in order to understand the range of issues.

Household surveys of current and potential grey water quantities as well as of water management and activities were conducted among participants from each community of the study area. Material on local practice with regards to water use and management was also examined to determine the impact on grey water disposal and use.

The questionnaire was based on the following questions:

General house hold information

- House type
- Income
- Occupation
- Number of occupants in the house

Available services

- Sanitation Type
- Distance to water sources
- Water use
- Detergents use

Grey water Management

- Disposal method
- Perception of water use

The volumes of grey water consumed were calculated from the recorded amount of water consumed per house hold. In the absence of any formal metering, the figures for water consumption were based on estimates given by the occupants themselves (usually by the number of buckets of water collected during each day).

The following key aspects were considered as the most important in terms of identifying representative communities for grey water investigation:

- Water consumption (litres / person/ day)
- Density of population
- Income
- Dwelling type
- Water supply

Once the target communities were selected, the following steps were taken before conducting the survey:

- Information on water supply was obtained from the eMalahleni Municipal database.

- The relevant local authorities were contacted for contact details of the councillor and local officials responsible for the settlement and to obtain any background information on water supply, sanitation issues, and strategies regarding grey water management.

- Where possible, meetings were held with relevant officials and community leaders in the area to discuss the aims of the research as well as the expected outcomes.

- Before conduction of the survey the grey water sampling arrangements were confirmed, and arrangements were made with the laboratory for sample bottles and instructions where necessary.

5.2.1 Correlation between quantity of grey water and water consumption

One of the objectives of this study was to quantify the generated grey water in the areas of Witbank. The generation of grey water is directly related to the consumption of water in a household and also dependent on a number of factors including the level of service provision.

The estimated household water use of Witbank as determined by the survey conducted throughout Witbank was found to vary from 20L-200L per day with a daily average of 102L/du. This however does not reflect the total amount of water delivered to the communities as leaks, were not accounted for.

Figures for grey water return factors in the literature vary widely ranging from 65% to 85%. In the absence of definitive measurements of grey water generation, the decision was taken to adopt an average grey water return factor of 75%. This figure was applied to the average water consumption to determine quantities of grey water produced in each area.

5.2.2 Background information

A total of 100 questionnaires were distributed to household water users in the city Witbank. Out of this total, 32 questionnaires were fully completed and returned giving a response rate of 32%. A low response rate is not advisable as it can undermine the ability to generalize the results to the larger target audience. A low response rate can also be indicative of a nonresponse bias within the sample (Aday, 2011). However, the response rate of 32% that was achieved in this study is acceptable given that the minimum of 30% is satisfactory according to Fowler (2013).

Table 5.1 below indicates distribution of participants across locations within Witbank City. A total of 8 out of 32 participants (representing 25% of the total) were based in upscale development parts of Witbank. Participants from the business district (central areas), townships and the neighbourhoods (city) contributed 25% each to the total number of households that participated in this survey as shown.

Table 5. 1: Distribution of participants across locations within Witbank City

Location	Frequency	Percentage
Upscale	8	25
Central	8	25
Township	8	25
City	8	25
Total	**32**	**100**

5.2.3 Descriptive statistics related to water usage and grey water production

This subsection provides descriptive statistics on income levels, average house hold water use, average household grey water produced and average per capita water use across location in Witbank. Table 5.2 below demonstrates average income, water usage and grey water production values for upscale, business district (central areas), township and neighbourhoods (city) areas of Witbank.

Based on the data that was collected in the survey, the water consumption of upscale development areas was the highest with of 122.5litres per household per day, followed by the business district (central areas) with an average of 76.3 litres. Correspondingly, the average grey water production of upscale development areas was also the highest at 93.1 litres per household per day. However, business district (central areas) had the highest average percentage grey water of 76.3% for every litre of water consumed compared to the 76.0% of upscale development areas.

It is observed from Table 5.2 that water consumption of households in townships was the lowest, with an average score of 52.5litres per day, while the neighbourhood's dwellers were second from the bottom consuming an average of 56.3 litres per household. Predictably, neighbourhood dwellers produced on average more grey water per household (75.8%) compared to the township dwellers that recorded the lowest average of 75.2%.

Upscale development areas had the highest average household income of R88 875 per month while communities in central areas (business district) part of Witbank recorded the second highest average household income of R22 250 per month. City dwellers had the lowest average income of R5 313 per month.

Table 5.2: Household water consumption, grey water production and income patterns across locations

Location	Income	Household water usage/L	Grey water Produced (litres)	%Grey water Produced
Upscale	88,875	122.5	93.1	76.0
Central	22,250	76.3	58.1	76.3
Township	6,125	52.5	39.4	75.2
City	5,313	56.3	42.5	75.8

5.2.4 Pairwise correlations between income, water consumption and grey water production

The association between income, water consumption and grey water production is discussed with reference to Chi Square test and linear regression.

The association between income and grey water production was tested using the Chi Square test as demonstrated in Table 5.3 below. A Chi-Square p value that is less than 0.05 means that an association between variables under investigation exists while a Chi-Square p value of more than 0.05 means that there is no association between the variables concerned.

Since the assumption of a minimum expected count 20% of the Chi Square test (X^2) was not violated, the Pearson X^2 test was applicable instead of the Likelihood Ratio test. It is observed in Table 3 that the Pearson X^2 p value of 0.025 is less than the 0.05 threshold. It can therefore be concluded that there is statistical evidence to suggest that a significant ($p < 0.05$) association exists between income and grey water production.

Table 5.3: Testing the association between income and grey water production using the Chi -Square

Test	Value	df	Asymp. Sig
Pearson Chi-Square	3.23E+02	275	0.025
Likelihood Ratio	133.603	275	1.000
Linear-by-Linear Association	22.048	1	0.000

Cramer's V in Table 5.4 shows the magnitude of association between income and grey water production for communities in Witbank. Cramer's V ranges from -1 to +1. The higher the Cramer's value the greater the association between variables of interest. Based on Table 5.4, it can be concluded that the association (with a Cramer's value of 0.958) between income and grey water production is positive and high.

Table 5.4: Magnitude of the association between income and grey water production

Nominal by Nominal	Phi	3.176
	Cramer's V	0.958
N of Valid Cases		32

The association between income and water consumption was also tested using Chi square test as demonstrated in Table 5.5 below. Since the assumption of a minimum expected count of 20% of the Chi squared test (X^2) was not violated, the Pearson X^2 test was applicable instead of the Likelihood Ratio test.

It is observed in Table 5.5 that the Pearson X^2 p value of 0.017 is less than the 0.05 threshold. It can therefore be concluded that there is a statistical evidence to suggest that a significant ($p < 0.05$) association exist between income and water consumption.

Table 5.5: Testing the association between income and water consumption using the Chi-Square test

Test statistics	Value	df	Asymp. Sig
Pearson's Chi-Square Test	3.54E+02	300	0.017
Likelihood Ratio	140.333	300	1.000
Linear-by-Linear Association	22.007	1	0.000

Cramer's V in Table 5.6 shows the magnitude of association between income and water consumption for communities in Witbank. Based on Table 5.6, it can be concluded that the association (with a Cramer's value of 0.96) between income and water consumption is positive and high.

Table 5.6: Magnitude of the correlation between income and water consumption

Nominal by Nominal	Phi	3.326
	Cramer's V	0.96
N of Valid Cases		32

The correlation between income, water consumption and grey water production is discussed with reference to linear regression where income (X) was the independent variable while water used and grey water produced were dependent variables (Y).

Figure 5.1 shows a plot of household income and water demand or usage for communities in Witbank. The plot indicates that as income levels increase, household water demand or usage within the communities also increases. A linear regression trend line was fitted to the plot as illustrated in Figure 5.1. The regression model had a high coefficient of determination (R^2) of 71.9% with a low standard error of 16.07. This means that about 72% of the variance in water usage was predictable from income.

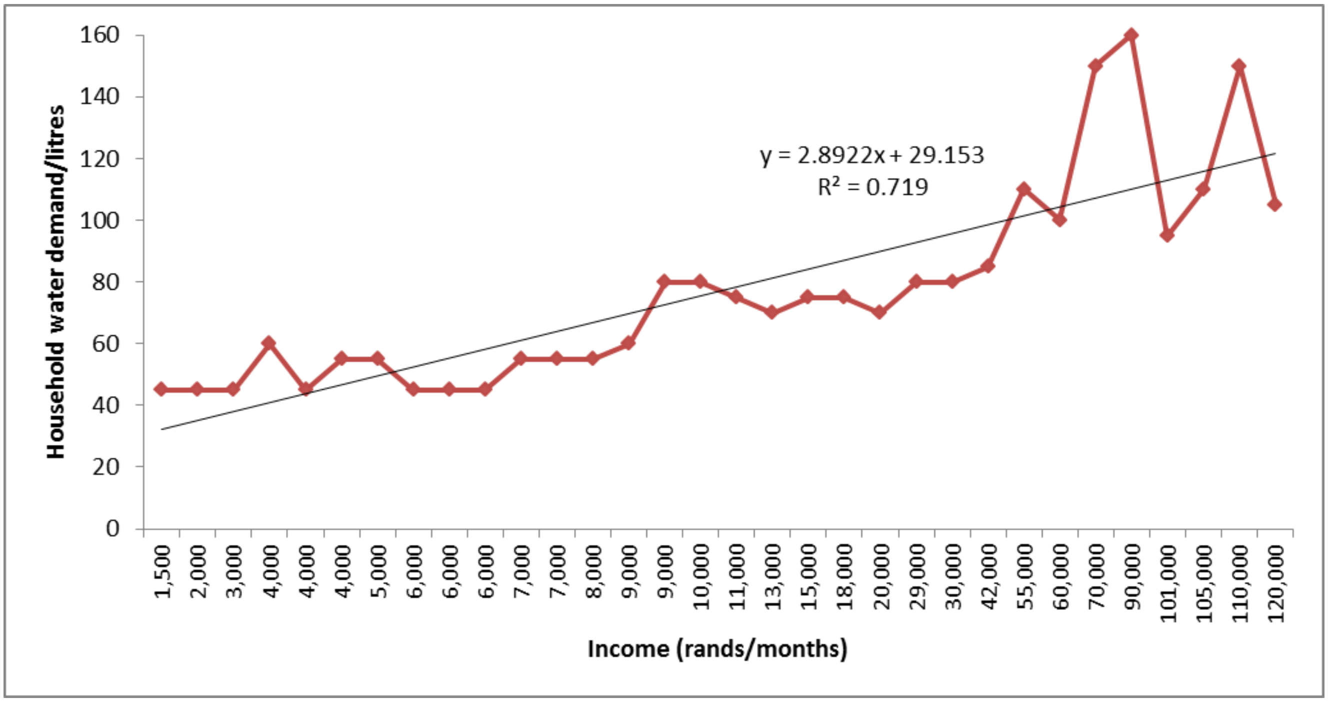

Figure 5. 1: The correlation between water demand and income

Figure 5.2 shows a plot of household income and grey water production within Witbank communities. The plot indicates that as income levels increase, grey water production within the communities also increases. A linear regression trend line was also fitted to the plot as illustrated in Figure 5.2. The regression model had a high coefficient of determination (R^2) of 71.8% with a low standard error of 12.30. This means that about 72% of the variance in grey water production was predictable from income.

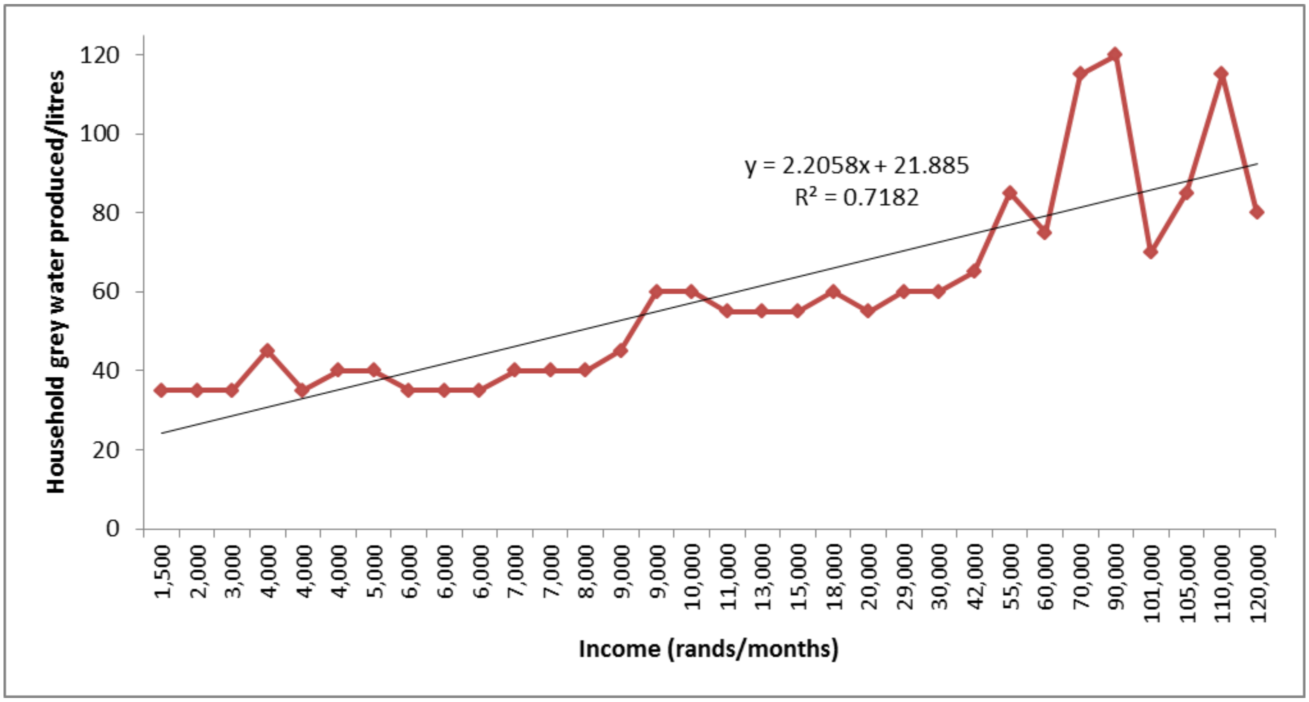

Figure 5. 2: The correlation between grey water production and income

Based on the above analysis, it can be concluded that grey water production is depended on volume of water consumed and income levels of inhabitants. Furthermore, the amount of grey water produced is influenced by the location of household consumers. Townships produced the least amount of grey water per given volume This is followed by household water consumers located in neighbourhoods, upscale developments, and business district areas produces the highest amount of grey water per given volume.

5.2.5 Comparison of income, water consumption and grey water production across location

Table 5.7 below shows the Analysis of Variance results of the comparison of income, water consumption and grey water production across Witbank locations (that included upscale development, neighbourhoods (city), townships and business district(central)-

areas). Analysis of Variance is a statistical procedure that is used to determine whether there are any significant differences between the means of three or more independent cohorts or groups of a population. Analysis of Variance uses F test and p values to statisticaly test equality of means. P values of less than 0.05 imply that significant differences in means exists among groups under investigation while the opposite hold true as well.

Basesd on the Analysis of Variance (ANOVA) results in Table 5.7, it can be observed that the p value of income variable is less than the 0.05 threshold. Hence it can be concluded that there is statistical evidence to suggest that the mean income of the upscale development, neighbourhoods, townships and business district areas differs significantly ($p < 0.01$) . In the same manner, the mean water usage per capita, household water consumption and grey water production across locations (upscale development, neighbourhoods, townships and bisiness district) in Witbank differ significantly ($p < 0.05$). However, there was no statistical evidence to suggest any significant differences in percentage of grey water production across locations.

Table 5.7: Determination of differences in means across locations using ANOVA

Parameter		Sum of Squares	df	Mean Square	F	Sig.
Income	Between Groups	3.76E+10	3	1.25E+10	69.71	0.000
	Within Groups	5.04E+09	28	1.80E+08		
	Total	4.27E+10	31			
Water Use/Capita	Between Groups	3.62E+02	3	120.708	3.62	0.025
	Within Groups	9.33E+02	28	33.312		
	Total	1.29E+03	31			
Household Water Use	Between Groups	2.48E+04	3	8270.833	33.44	0.000
	Within Groups	6.93E+03	28	247.321		
	Total	3.17E+04	31			
Grey water Produced	Between Groups	1.46E+04	3	4854.948	34.72	0.000
	Within Groups	3.92E+03	28	139.844		
	Total	1.85E+04	31			

%Grey water Produced	Between Groups	5.09E+00	3	1.696	0.36	0.780
	Within Groups	1.31E+02	28	4.668		
	Total	1.36E+02	31			

Pairwise comparison of group means was performed using the t-test. This was done in order to determine if there were any significant differences across locations (pairwise) on income, water usage per capita, household water consumption and grey water production. Thus upscale development areas and other areas (business district, neighbourhood and townships) were compared on income, water usage per capita, household water usage and grey water production (as shown in Table 5.8). It can be observed in Table 5.8 that the average values for water usage per capita of the upscale development and business disctrict area pairing on the one hand and the, upscale developments and townships area pairing on the other hand were not significantly ($p > 0.05$) different. However,the mean values of all the other remaining pairwise comparisons were significantly ($p < 0.01$) different as demonstrated in Table 5.8. This might imply that the differences in grey water production across locations is due to differences in lifestyles.

Table 5.8: Comparison of upscale development areas with other locations on income, water usage and grey water the using t-test

Parameter	Location	N	Mean	T Value	Sig.
Income	Upscale	8	8.9E+04	7.09	0.000
	Central	8	2.2E+04		
Water Usage/Capita	Upscale	8	2.2E+01	1.11	0.288
	Central	8	1.8E+01		
Household Water Usage	Upscale	8	1.2E+02	9.90	0.001
	Central	8	7.6E+01		
Grey water Produced	Upscale	8	9.3E+01	4.83	0.002
	Central	8	5.8E+01		
Income	Upscale	8	8.9E+04	9.57	0.000
	Township	8	6.1E+03		
Water Usage/Capita	Upscale	8	2.2E+01	2.01	0.064
	Township	8	1.5E+01		

Household Water Usage	Upscale	8	1.2E+02	7.34	0.000
	Township	8	5.3E+01		
Grey water Production	Upscale	8	9.3E+01	7.38	0.000
	Township	8	3.9E+01		
Income	Upscale	8	8.9E+04	9.61	0.000
	City	8	5.3E+03		
Water Usage/Capita	Upscale	8	2.2E+01	2.92	0.019
	City	8	1.3E+01		
Household Water Usage	Upscale	8	1.2E+02	6.18	0.000
	City	8	5.6E+01		
Grey water Production	Upscale	8	9.3E+01	6.23	0.000
	City	8	4.3E+01		

Table 5.9 below compares average income, water usage per capita, household water consumption and grey water production values for the neighbourhood, township and business district areas of Witbank using a t-test. The t-test indicates that the average values for water usage per capita of all pairwise combinations (central-City, central-township, City-Township) were not significantly different ($p > 0.05$). In addition, were the values for income levels of neighbourhood and township areas, household water usage (for neighbourhood and township) as well as grey water produced (of neighbourhood and township) not significantly different. However, the remaining pairwise combinations showed significant mean value differences ($p < 0.05$) as demonstrated in Table 5.9. The differences in grey water production can also be attributed to differences in lifestyles across locations.

Table 5.9: Comparison of neighborhood, business district and Townships areas on income, water usage and grey water production using the t-test

Parameter	Location	N	Mean	T Value	Sig.
Income	Central	8	2.2E+04	4.25	0.001
	Township	8	6.1E+03		
Water Usage /Capita	Central	8	1.8E+01	1.15	0.270
	Township	8	1.5E+01		
Household Water Usage	Central	8	7.6E+01	8.05	0.000
	Township	8	5.3E+01		
Grey water Production	Central	8	5.8E+01	9.49	0.000
	Township	8	3.9E+01		

Income	Central	8	2.2E+04	4.34	0.001
	City	8	5.3E+03		
Water Usage /Capita	Central	8	1.8E+01	2.34	0.052
	City	8	1.3E+01		
Household Water Usage	Central	8	7.6E+01	3.50	0.004
	City	8	5.6E+01		
Grey water Production	Central	8	5.8E+01	8.58	0.005
	City	8	4.3E+01		
Income	Township	8	6.1E+03	0.63	0.541
	City	8	5.3E+03		
Water Usage /Capita	Township	8	1.5E+01	0.90	0.385
	City	8	1.3E+01		
Household Water Usage	Township	8	5.3E+01	-0.64	0.539
	City	8	5.6E+01		
Grey water Production	Township	8	3.9E+01	-0.75	0.472
	City	8	4.3E+01		

Based on the analysis above, it can be concluded that income, water usage per capita, household water consumption and grey water production across locations for Upscale development, neighbourhood, Townships and business district areas were significantly different.

5.2.6 Quantification of resource recovery

Table 5.10 shows resource content in untreated grey water that was sourced from Witbank households. Untreated grey water recorded an average of 3.45 mg/L and 0.39mg/L of nitrates and nitrites respectively. Although the average nitrates content that was recorded in this study fell within the theoretical range of between 1.56mg/L and 10.7mg/L (Finley, 2008) and within the specifications of the Department of Water Affairs, it fell outside the National Standards range of less than 1.5mg/L. The nitrites average of 0.39 mg/L that was recorded in this study was lower than the Department of Water Affairs and National Standards range of 1.5 to 16 mg/L, but recorded a moderately high standard deviation that was about 17.9% of the mean. The nitrite content in untreated grey water was also outside the theoretical range of between 10mg/L and 35mg/L (Devotta, 2007).

The average ammonium content in untreated grey water of 0.5 mg/L was lower than the Department of Water Affairs range but within the National Standards range of less than 1.0 mg/L. The ammonium content in untreated grey water was much lower than to the theoretical range of between 300mg/L and 1400mg/L (Devotta, 2007). On the other hand, the average phosphorus content in untreated grey water of 4.20mg/L was within the theoretical specifications of between 5mg/L and 30mg/L and also within the Department of Water Affairs range, but was much higher than the National Standards range of less than 1.0mg/L. Phosphorus data values were significantly spread with a Standards deviation of about 26.2% of the mean value. The average nitrogen content in untreated grey water of 20.5mg/L was way higher than the ranges of the Department of Water Affairs and the National Standards. The average nitrogen content in untreated grey water was also higher than a theoretical upper limit of 17.2mg/L (Hernandez et al., 2008).

Table 5. 10: Resource content in untreated grey water from Witbank

Parameter	Replication	Mean	STD Deviation	DWA	National standard
Nitrate (mg/l)	9	3.45	0.33	1.5-15	< 1.5
Nitrite (mg/l)	9	0.39	0.07	1.5-16	1.5-16
Ammonia (mg/l)	8	0.50	0.14	2-3	< 1.0
Nitrogen (mg/l)	9	20.50	0.75	1.5-15	< 5.0
Phosphorus (mg/l)	9	4.20	1.10	2.5-10	< 1.0

Table 5.11 below shows the quantities of resources that were recovered the after treatment process had been carried out. It was observed that considerable quantities of potassium- amounting to 1.742mg/L- were recovered. This process also recovered fair quantities of Nitrogen, phosphorus and nitrate of about 0.174mg/L, 0.021mg/L and 0.036mg/L respectively. However, negligible quantities of ammonium were recovered after the treatment process. No quantities of nitrites were recovered after the treatment process.

Table 5. 11: Quantities of resources recovered in mg/L

Resource	Mean (mg/L)	STDEV
Nitrogen	0.174	0.059
Phosphorus	0.021	0.007
Potassium	1.742	0.594
Nitrate	0.036	0.012
Nitrite	0.000	0.000
Ammonia	0.006	0.002

5.3 Quantitative analysis of data from experimental study

This subsection provides a detailed analysis of data that was gathered from experimentation before and after treatment of grey water.

5.3.1 Discussion of characteristics of untreated grey water from Witbank

This subsection provides a discussion on the characteristics of untreated grey water. Physical, chemical, operational alert, resources content and microbiological characteristics were considered in this study. The results of each of the above mentioned characteristics are discussed below.

5.3.1.1 Discussion of physical characteristics of untreated grey water

The physical quality of grey water parameters that were measured in the study included pH, total suspended solids, turbidity and conductivity. PH measures the degree of acidity or alkalinity of grey water and ranges from 0 to 14. A pH of less than 7 indicates acidity while a PH of above 7 indicates alkalinity (Carden et al., 2007). According to Qishlaqi et al. (2008), high levels of pH indicate risks of clogging, which could have negative effects on plant growth and soil quality. Likewise, low pH levels indicate that the water is acidic, corrosive, and a hazard to human, plant and sea life. The Department of Water Affairs stipulates that a pH between 5.5 and 9.5 is an acceptable standard for grey water.

Total suspended solids are inorganic material or particles that are often found floating in water and can include sediment, silt, sand, plankton and at times algae. Total suspended solids are influence clarity of water. Generally, when there are more total suspended solids, there is less water clarity and vice versa (Sheikh, 2010). Closely related to total suspended solids in water is turbidity which is also used to measure the degree of water clarity, but includes suspended solids as well as dissolved coloured material. As a consequence of this, turbid water appears cloudy and murky (Nagata and Funamizu, 2009). It is also important to measure the ability of grey water to conduct electricity as it indicates salt contents. The higher the salt contents in grey water, the higher the level of electrical conductivity (Al-Zu'bi & Al-Mohamadi, 2008).

Table 5.12 demonstrates the physical characteristics of untreated grey water that was sourced from Witbank households. In order to obtain credible results, each parameter was replicated 9 times. The average of pH of untreated grey water sourced from Witbank was pH of 6.92 with a low standard deviation of about 1.4% of the mean. The average pH of the untreated grey water was within the range of the Department of Water Affairs and within National Standards expectations as indicated in Table 5.11. Even though the average pH of untreated grey water was within standard limits, it showed that the untreated grey water from Witbank was slightly acidic. This is attributable to the fact that Witbank has many of mines that contribute the acidic waste water they produce to the sources of water. The average pH (of 6.92) of grey water obtained in this study is supported by literature theory, which suggested that grey water should be between 6.5 and 8.5 (Devotta, 2007; Finley, 2008).

The Average total suspended solids and the turbidity of untreated grey water from Witbank were high at 98.14 mg/L and 606.35 NTU respectively. The total suspended solids of untreated grey water had a slightly higher standard deviation of about 14.9% of the mean. The turbidity of untreated grey water was outside the Department of Water

Affairs and National Standards specifications as shown. Result obtained for total suspended solids in grey water in this study were also outside the limit of 150 – 400mg/L that was suggested by theory (Devotta, 2007). The turbidity of untreated grey water obtained in this study was well above the 69 NTU that was expected in theory (MPMSAA and RMIT University, 2008).

The average conductivity of untreated grey water obtained in this study was high at 444.11 mS/m with a low standard deviation of 1.78% of the mean. It was also way above the upper limits of the Department of Water Affairs and the National Standards of 150 mS/m and 250 dS/m respectively. The results on conductivity of untreated grey water of this study were also outside the theoretical boundaries as suggested by Devotta (2007).

Table 5. 12: Physical characteristics of untreated grey water from Witbank

Parameter	Replication	Mean	STD Deviation	DWA	National standard
PH	9	6.92	0.10	5.5-9.5	5.5-7.5
Turbidity (NTU)	7	606.35	28.07		
Conductivity (mS/m)	7	444.11	7.89	50-150	< 250
Total Suspended Solids (mg/L)	9	660.50	98.14	10-25	< 90

5.3.1.2 Discussion of chemical characteristics of untreated grey water

Chemical Oxygen Demand (COD) is as much as the Biochemical Oxygen Demand (BOD) an important water quality parameter that provides a measure of the effect of the discharged water to the environment. Chemical Oxygen Demand is also a good measure of the capacity of water to take in oxygen during the decomposition process of organic compounds and oxidation of inorganic elements (Sarkar, 2014). The higher the amount of Chemical Oxygen Demand the greater the amount of pollution in the sample under test.

Phosphorus and nitrogen are according to Jefferson (2008), are essential nutrients for plant growth. However, phosphates are also responsible for excessive plant growth, eutrophication of surface waters and nitrate contamination of groundwater. Jefferson (2008) further confirmed that iron is necessary for healthy plant growth. A deficiency in iron deprives the plant of oxygen and can be observed in its leaves that are yellow and sickly instead of green leaves. Likewise, manganese is used by plants for photosynthesis, respiration and assimilation of nitrogen. A too high availability of manganese in water or plants is toxic for plant growth while a deficiency in manganese has negative effects on photosynthesis and can also be observed in the plant's yellow leaves.

Table 5.13 shows the chemical characteristics of untreated grey water that was sourced from Witbank households. In order to obtain credible results, each parameter was replicated 9 times. The COD level of untreated grey water were high levels with an average of 565.25 mg/L which is above the theoretical range of between 161mg/L and 435mg/L (Finley, 2008). The COD values had a low standard deviation of about 6.6% of the mean. The average COD content of untreated grey water was way above the standard range specified by the Department of Water Affairs and National Standards as indicated in Table 5.12.

Untreated grey water recorded low orthophosphate levels with an average of 2.28 mg/L but with a high standard deviation of about 15.8% of the mean. The average orthophosphate levels of untreated grey water were within the ranges of the Department of Water Affairs and National Standard. Untreated grey water recorded low dissolved iron and manganese content that were within the ranges of the Department of Water Affairs and National Standard. The dissolved iron content of less than 0.3mg/L that was obtained in this study was still above the limit of less than 0.11mg/L that was expected in theory (Hernandez, Leal, Zeeman, Temmink, Buisman, 2008). However, oil, grease and soap content in untreated grey water was very high at 1271.75 mg/L compared to the Department of Water Affairs and National Standard of less than 2.5 mg/L. Despite these high oil, grease and soap contents in untreated grey water, the standard deviation was low at about 6.4% of the mean.

Table 5. 13: Chemical characteristics of untreated grey water from Witbank

Parameter	Replication	Mean	STD Deviation	DWA	National standard
COD (mg/l)	9	565.25	37.41	30-75	< 75
Orthophosphate (mg/L)	9	2.28	0.36	2.5-10	< 1.0
Oil,Grease, Soap	9	1,271.75	80.94	< 2.50	< 2.5
Dissolved Iron (mg/L)	9	< 0.30	0.00	< 0.30	< 0.3
Dissolved Manganese (mg/L)	9	<0.20	0.00	< 0.10	< 0.1

5.3.1.3 Discussion of operational alert characteristics of untreated grey water

Table 5.14 shows the operational alert characteristics of the untreated grey water that was sourced from Witbank households. In order to obtain credible results, each parameter was replicated 9 times. Alkalinity levels in untreated grey water were high averaged 938.25 mg/L and had a low standard deviation of about 2.98% of the mean. The average alkalinity level of untreated grey water was way above the standard range specified by the Department of Water Affairs as indicated in Table 5.13 and was also above the theoretical upper limit of 203mg/L.

Chloride levels in untreated grey water were high and averaged 505 mg/L compared to the maximum of 100 mg/L stipulated by the Department of Water Affairs. The chloride levels in untreated grey water were also much higher than the theoretical limit of less than 19mg/L (Sarkar, 2014). The average sulphate and sodium content in untreated grey water were high at of 1529 mg/L and 1545 mg/L respectively. Both the sulphate and sodium content in untreated grey water were above the National Standard values of less than 1000 mg/L and 460 mg/L respectively. The sulphate content in the untreated grey water that was obtained in this study was way above the upper limit of 154mg/L

(Sarkar, 2014). The sodium content in the untreated grey water was also outside the theoretical range of between 70mg/L and 300mg/L. The calcium content in the untreated grey water was slightly high and averaged of 62 mg/L compared to a theoretical upper limit of 60.79mg/L.

Aluminium and potassium content in the untreated grey water were low and averaged 0.22 mg/L and 37.5 mg/L respectively. The average aluminium and potassium contents in the untreated grey water being recorded in this study were within National Standard values of less than 20 mg/L and 50 mg/L respectively. Potassium content in untreated grey water should according to Finley (2008), be between 0.6mg/L and 4.4mg/L. Aluminium data values had a high standard deviation which of 22.7% of the mean. The spread of data values from the mean for Potassium were moderate with a standard deviation which of 15.4% of the mean. Calcium content in untreated grey water recorded an average of 62.0 mg/L with a high standard deviation which of 23.5% of the mean.

Table 5. 14: Operational alert characteristics of untreated grey water from Witbank

Parameter	Replication	Mean	STD Deviation	DWA	National standard
Aluminium (mg/l)	9	0.22	0.05		< 20
Alkalinity (mg/l)	9	938.25	27.92	20-100	
Calcium (mg/l)	9	62.00	14.56		
Chloride (mg/l)	9	505.00	50.99	100	100-350
Potassium (mg/l)	9	37.75	5.81		< 50
Sulphate (mg/l)	9	1,529.00	153.39		< 1000
Sodium (mg/l)	9	1,545.00	98.26	70.0	70-460

5.3.1.4 Discussion of microbiological determinants in untreated grey water

Table 5.15 shows microbiological determinants in untreated grey water that was sourced from Witbank. E coli, total coliforms (per 100ml) and heterotrophic plate count recorded high averages that were well above the Department of Water Affairs and the National Standard range of a maximum of 1000 units in each case. The heterotrophic plate count in particular was more than 7 times above the maximum standard range while E coli and total coliforms (per 100ml) were about 2.4 times above the maximum. The presence of total coliforms in untreated grey water was also above the theoretical specifications of between 600mg/L and 728mg/L (Friedler, 2004).

Table 5. 15: Microbiological determinants in untreated grey water from Witbank

Parameter	Replication	Mean	STD Deviation	DWA	National standard
E coli	9	>2420	0.00	< 1000	< 1000
Total Coliforms (per 100ml)	9	>2420	0.00	< 1000	< 1000
Heterotrophic Plate Count	9	>7380	0.00	< 1000	< 1000

In summary, the results indicated that untreated grey water in Witbank is acidic. The presence of total suspended solids, as well as the turbidity and conductivity of untreated grey water within the city of Witbank is high. Both turbidity and conductivity of untreated grey water in Witbank were found to be outside the limits of the Department of Water Affairs and National Standards.

Untreated grey water from Witbank recorded low orthophosphate levels that were within the Department of Water Affairs and National Standard ranges. Again, untreated grey water from Witbank recorded low dissolved iron and manganese content that were also within the Department of Water Affairs and National Standard ranges. However, COD, oil, grease and soap content in untreated grey water from Witbank was very high and were outside the ranges of the Department of Water Affairs and National Standards.

Sulphate, sodium and chloride contents in untreated grey water from Witbank were high and outside the limits of the Department of Water Affairs. However, aluminium and potassium content in untreated grey water were low and were within National standard values. On the other hand, the E coli, total coliforms (per 100ml) and heterotrophic plate count in the untreated grey water from Witbank were all high and well above the ranges of the Department of Water Affairs and the National Standard.

5.3.1.5 Discussion of characteristics of untreated grey water according to area within Witbank

Untreated grey water was collected from the upscale development, neighbourhood, and business district and townships areas of Witbank in Mpumalanga province. This subsection compares untreated grey water according to the above mentioned areas of collection.

5.3.1.6 Discussion of physical characteristics of untreated grey water according to area of source within Witbank

Figure 5.3 below compares the physical characteristics of untreated grey water according to the area of source within Witbank. Grey water from the Central areas of Witbank was more turbid recording a mean of 613.5 NTU while grey water from townships in Witbank recorded the least turbidity of a mean of 586.5 NTU. Grey water that was sourced from the upscale developments and the city recorded almost similar averages of 602.7 and 606.4 NTU respectively. The turbidity of untreated grey water from all the source areas above was above the theoretical specifications in literature of less than 69 NTU (MPMSAA and RMIT University, 2008).

Conductivity of the untreated grey water followed a similar pattern to the one defined in turbidity. Whereas untreated grey water from the central areas recorded the highest mean conductivity of 459.5 mS/m, grey water from townships corded the lowest mean conductivity of 419.8 mS/m. The conductivity of untreated grey water from all the above mentioned source areas was above the theoretical specifications as well as those of Department of Water Affairs, National Standard (Devotta, 2007).

At a mean of 6661.5mg/L grey water sourced from the central areas of Witbank recorded the highest total suspended material content, followed closely by an average of 660.5 mg/L in grey water from the city followed closely with an average of 660.5 mg/L. Grey water from the Witbank townships contained the least total suspended material with an average of 607.5mg/L. Total suspended material in untreated grey water sourced from all the above locations were above theoretical specifications of between 150 mg/L and 400mg/L (Devotta,2007) as well as those of Department of Water Affairs, National Standards.

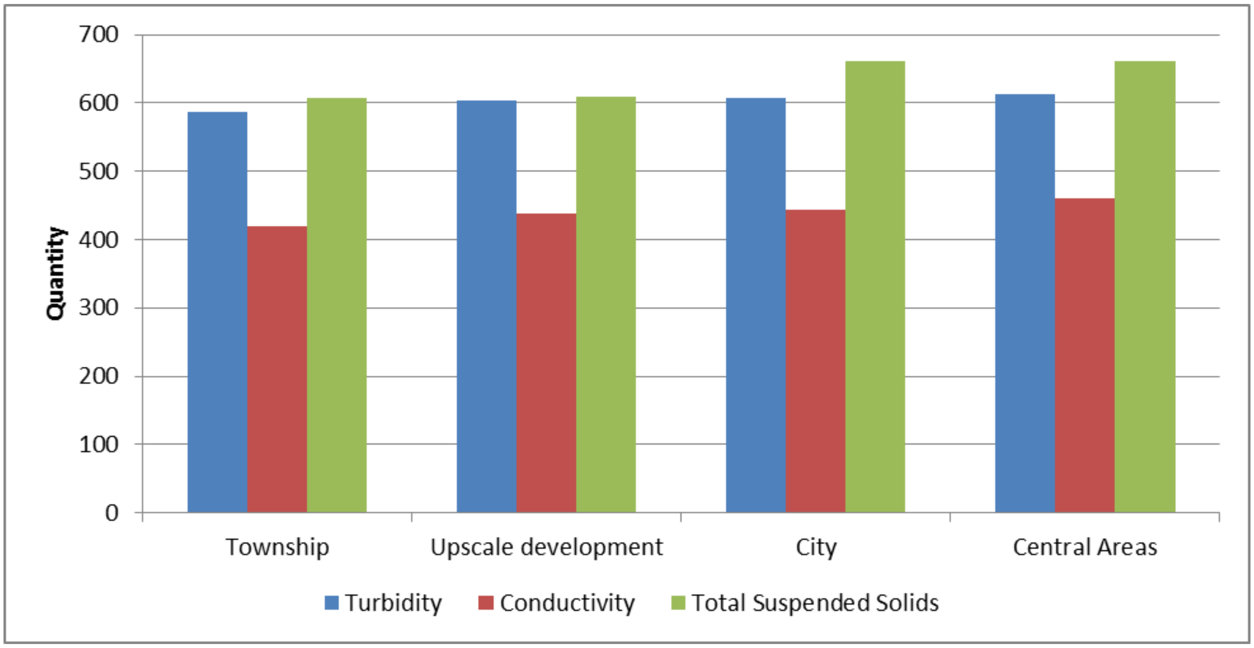

Figure 5. 3: Comparison of physical characteristics of grey water according to the area of source

5.3.1.7 Discussion of chemical characteristics of untreated grey water according to area of source within Witbank

Figure 5.4 below compares the chemical characteristics of untreated grey water according to the area of source within Witbank. Grey water from the Central areas of Witbank recorded the highest COD content of an average of 585.2 mg/L, followed closely by an average of 565.2 mg/L recorded in grey water from the city. However, untreated grey water from the townships in Witbank had the lowest average COD content of 513.3 mg/L which was well above theoretical specifications (Hernandez et al., 2008) and those of the Department of Water Affairs standard, and National Standards

Oil, grease and soap content in untreated grey water was heaviest in central areas of Witbank with an average of 1284.3 mg/L, followed closely by city areas that recorded an average of 1271.8mg/L. At an average of 1238.5mg/L, township areas of Witbank again recorded the lowest oil, grease and soap content in untreated grey water. A similar trend was established in the orthophosphate content in untreated grey water where Central areas of Witbank again recorded the highest orthophosphate content of about 2.4mg/L, followed by the city areas with an average of 2.3mg/L. Untreated grey water from the upscale development areas and the townships had recorded the same orthophosphate content of about 2.2mg/L.

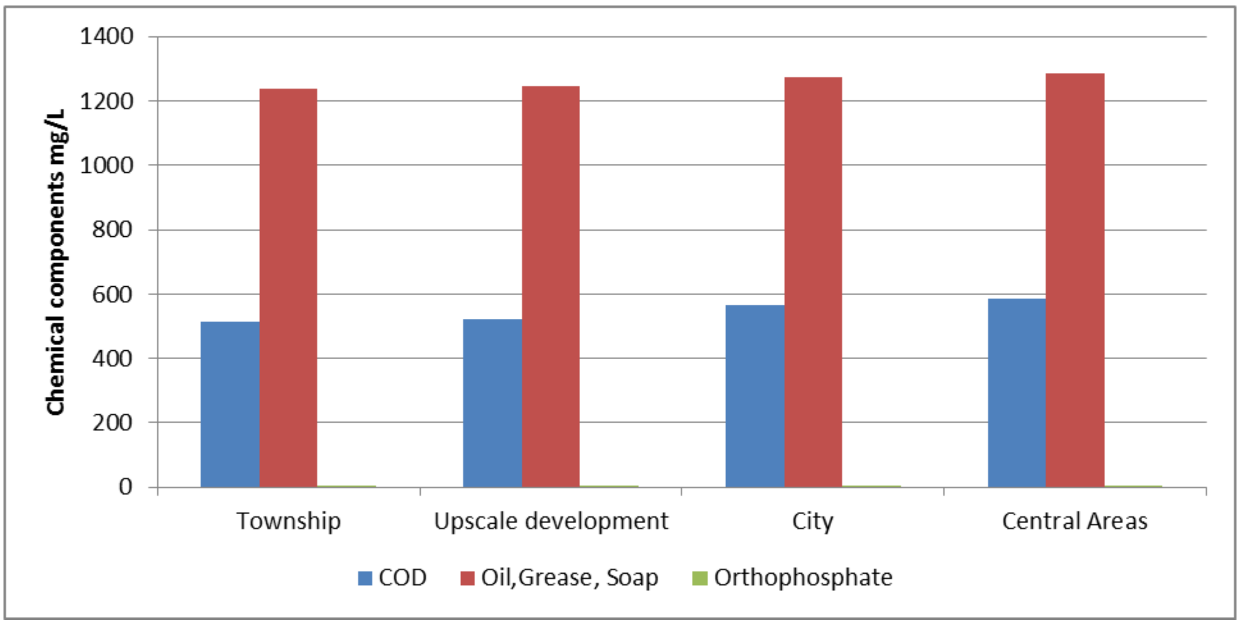

Figure 5. 4: Comparison of chemical characteristics of untreated grey water according to the area of source within Witbank

5.3.1.8 Discussion of operational alert characteristics of untreated grey water according to area of source within Witbank

Figure 5.5 below compares operational characteristics of untreated grey water according to the area of source within Witbank. Untreated grey water from the central areas of Witbank recorded the highest alkalinity levels of an average of 1004.3 mg/L while untreated grey water from the city followed closely with an average of 938.3 mg/L. However, untreated grey water from the townships in Witbank had the lowest alkalinity level of an average of 857.8 mg/L. This was still above the theoretical specifications of not more than 203mg/L (Kuntal, Sharma, Bhatia, Kazmi, 2009).

Untreated grey water from the central areas of Witbank recorded the highest chloride, sulphate and sodium contents averages of 509.8mg/L, 1608.5mg/L and 1554.8mg/L respectively. The second highest chloride, sulphate and sodium contents average of 505mg/L, 1529mg/L and 1545mg/L respectively were recorded in untreated grey water from the city. However, untreated grey water from the townships recorded the lowest chloride, sulphate and sodium contents averages of 455.3mg/L, 1512.3mg/L and 1512.5mg/L respectively. Chloride, sulphate and sodium contents in untreated grey water from the source areas mentioned above were all above specifications of the Department of Water Affairs, and National Standards as well as theoretical specifications of less than 19mg/L for chloride content in untreated grey water, (Sarkar, 2014). Less than 154 mg/L for sulphate content in untreated grey water- (Sarkar, 2014) and of between 70mg/L and 300mg/L for sodium content in untreated grey water, (Devotta, 2007).

Untreated grey water from the central areas of Witbank had the highest aluminium and potassium content with an average of 0.23mg/L and 38.5 mg/L respectively. The city areas of Witbank had the second highest aluminium and potassium content with an average of 0.22mg/L and 37.75 mg/L respectively while untreated grey water from the townships of Witbank had the least aluminium and potassium content with an average of 0.17mg/L and 36.75 mg/L respectively.

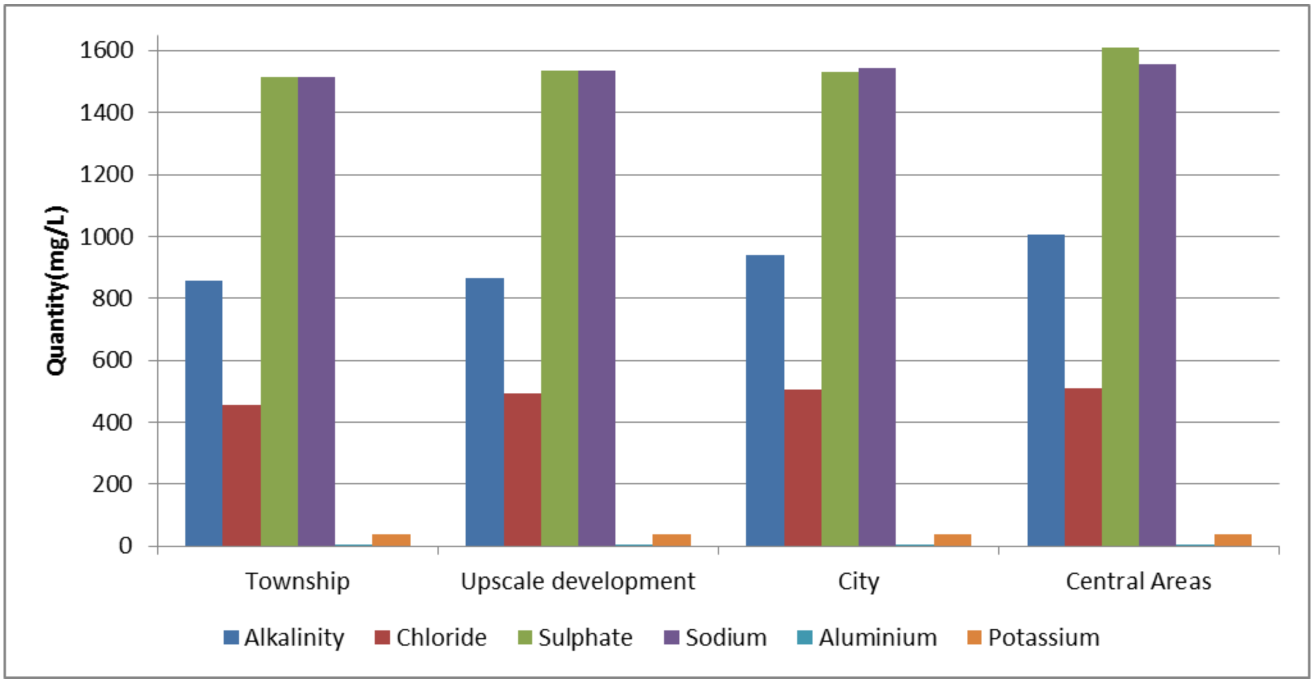

Figure 5. 5: Comparison of operational characteristics of untreated grey water according to the area of source in Witbank

5.3.1.9 Discussion of resource content in untreated grey water according to area

Figure 5.6 below compares content of resources in untreated grey water according to the area of source within Witbank. Untreated grey water from the central areas of Witbank had the highest ammonium, nitrate and nitrate content recording with averages of 0.53 mg/L, 3.58mg/L and 0.41mg/L respectively. Untreated grey water from the city areas of Witbank had the second highest ammonium, nitrate and nitrite content recording with averages of 0.50 mg/L, 3.45mg/L and 0.39mg/L respectively. However, untreated grey water from the townships in Witbank had the least ammonium, nitrate and nitrite content. The ammonium content in untreated grey water from the above source areas was within the National Standard expectations of less than 1.0mg/L but was above the standard range of values of the Department of Water Affairs and theoretical standard values as suggested by Devotta (2007).

Nitrite content from untreated grey water from all the source areas above were outside the specifications of the Department of Water Affairs, and National Standard as well as theoretical expectations as recommended by Devotta (2007). The average nitrate content in untreated grey water from all the source areas above were conformity of the Department of Water Affairs, National Standards and theoretical expectations as recommended by Finley (2008).

Grey water from the city had the highest nitrogen content of an average of 20.5mg/L while the untreated grey water from the central areas of Witbank had the second highest nitrogen content of an average of 20.0mg/L. This was above the maximum expected theoretical limit of 17.2mg/L (Hernandez, et al., 2008) and was also above the Department of Water Affairs and National Standard values.

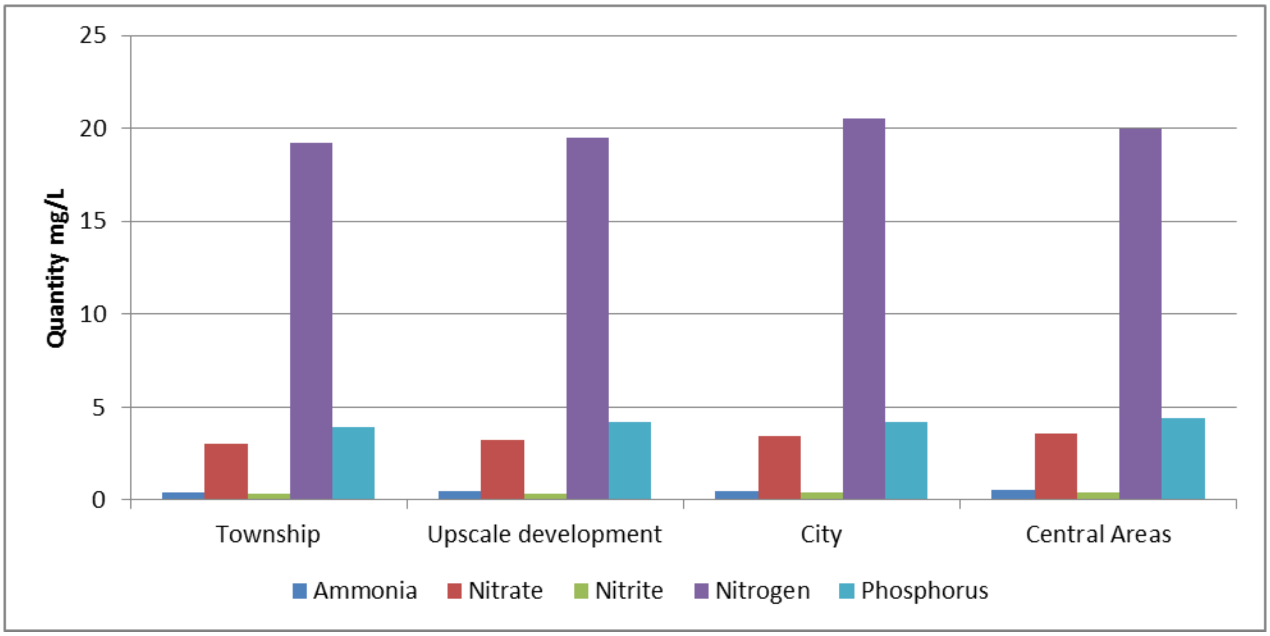

Figure 5. 6: Comparison of resource content in untreated grey water according to area in Witbank

In summary, the results indicated that grey water from the central areas of Witbank recorded the highest turbidity, total suspended material, COD, oil, grease and soap content, as well as orthophosphate content. However, grey water from the townships of Witbank had the least turbidity, total suspended material, orthophosphate content, and oil, grease and soap content. The turbidity, total suspended material, COD, oil, grease and soap content and orthophosphate content of untreated grey water from all the source areas in Witbank were above the specifications of the Department of Water Affairs.

Untreated grey water from the central areas recorded the highest mean conductivity of 459.5 mS/m while grey water from the townships had the least conductivity of 419.8 mS/m. The conductivity of untreated grey water from above the mentioned source areas were above the specifications of the Department of Water Affaires, National Standards.

Untreated grey water from the central areas recorded the highest chloride, sulphate and sodium content. However, untreated grey water from the townships had the least chloride, sulphate and sodium contents. Chloride, sulphate and sodium contents in untreated grey water from the above mentioned source areas were all above specification of the Department of Water Affairs, and National Standards.

Untreated grey water from the central areas of Witbank had the highest ammonium, nitrate and nitrate content. However, untreated grey water from the townships in Witbank had the least ammonium, nitrate and nitrite contents. Nitrites, ammonium and nitrates content in untreated grey water from all the source areas above were outside the standard of the Department of Water Affairs.

5.3.2 Discussion of characteristics of treated grey water from Witbank

This subsection provides a discussion on the characteristics of treated grey water. The physical, chemical, operational alert and resources content as well as microbiological characteristics were considered in this study.

Untreated grey water that was collected from users in Witbank was primarily subjected to physical and chemical treatment processes. The physical treatment processes involved aerobic screening and Multimedia Filtration (MMF). The multimedia filtration process as suggested by Najee (2007) was performed by using gravity to pass water through a porous medium of stone a granular bed of varying sizes and sand. Filtration process was specifically done for the removal of larger pathogens, such as protozoa, followed by bacteria, and then viruses, due to size exclusion.

After the filtration process, the grey water was subjected to an ultraviolet lamp. Ultraviolet disinfection provides a barrier against pathogens. Finally, chlorine (CL) residual was added to the recycled water to treat it and remove bad odours while in storage. The treatment processes that were applied in this study included Aerobic Screening (AS), Multimedia Filtration (MMF), Ultraviolet rays (UV) and Chlorination (CL). These processes were followed individually and in combinations. The quality of the treated grey water in terms of physical, chemical, operational alert and resource content was measured using appropriate apparatus.

5.3.2.1 Discussion of the physical characteristics of treated grey water

After subjecting grey water to individual and combination of Aerobic Screening (AS), Multimedia Filtration (MMF), Ultraviolet radiation (UV) and Chlorination (CL) processes, the physical characteristics of grey water which included pH, turbidity, conductivity and total suspended solids were measured.

Figure 5.7 below indicates the pH of grey water after various combinations of the treatment processes. It was observed that the highest average pH of 9.08 was achieved when grey water was treated using a combination of MMF and AS while the lowest average pH level of 8.20 was accomplished when grey water was treated using MMF only. Treating grey water with a combination of MMF, AS and UV also significantly increased its pH to 8.85. It was also observed that after each treatment process, the pH of treated grey water was significantly higher than the untreated grey water which recorded an average of 6.92. The pH values of water after treatment process using various combinations in Figure 5.7 were all within the standard stipulations of 5.5 to 9.5 of the Department of Water Affairs. However, none of the pH values in Figure 5.7 were within the limits of National Standards.

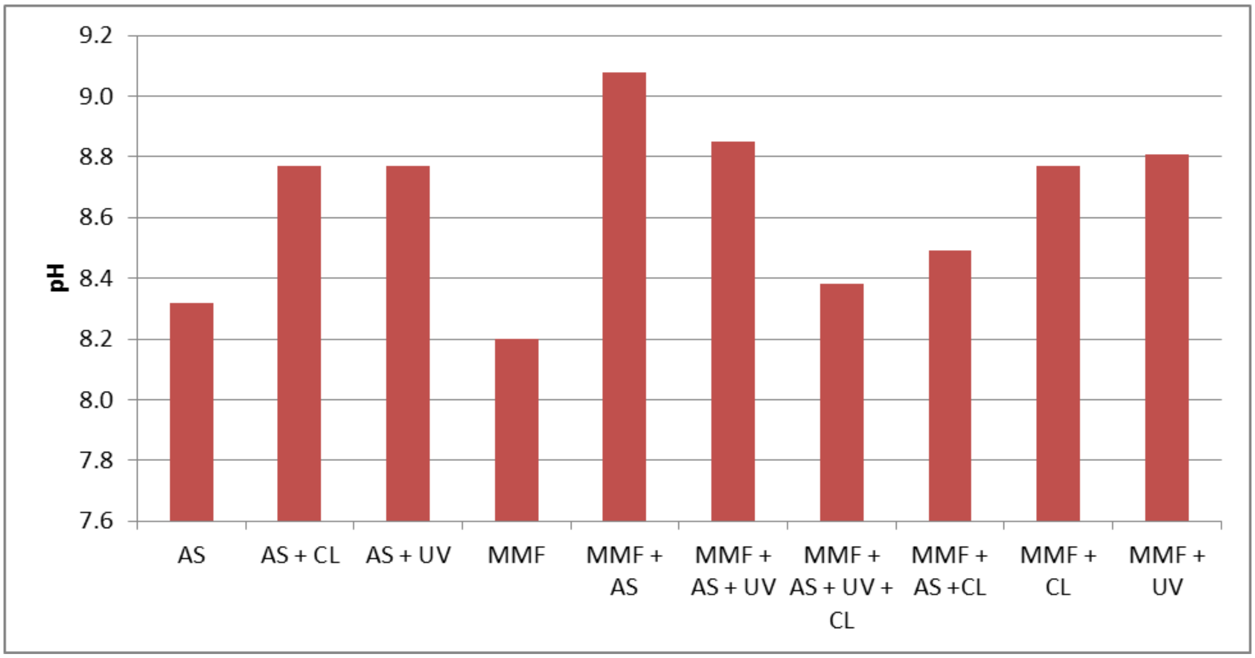

Figure 5. 7: pH of grey water after the treatment process using various combinations

Turbidity of grey water after the treatment process using various treatment combinations is demonstrated in Figure 5.8 below. It was observed that the highest average turbidity of 180.25 NTU was achieved when grey water was treated using a combination of AS and UV while the lowest average turbidity of 176.03 NTU was achieved when grey water was subjected to the Multimedia Filtration process only. It was also observed that grey water that was treated with a combination of MMF and UV recorded a high average turbidity of 180.06 NTU. Furthermore, it was noticed that after each treatment process, the turbidity of the treated grey water under the various combinations was considerably lower than the turbidity of untreated grey water which recorded an average of 606.35 NTU.

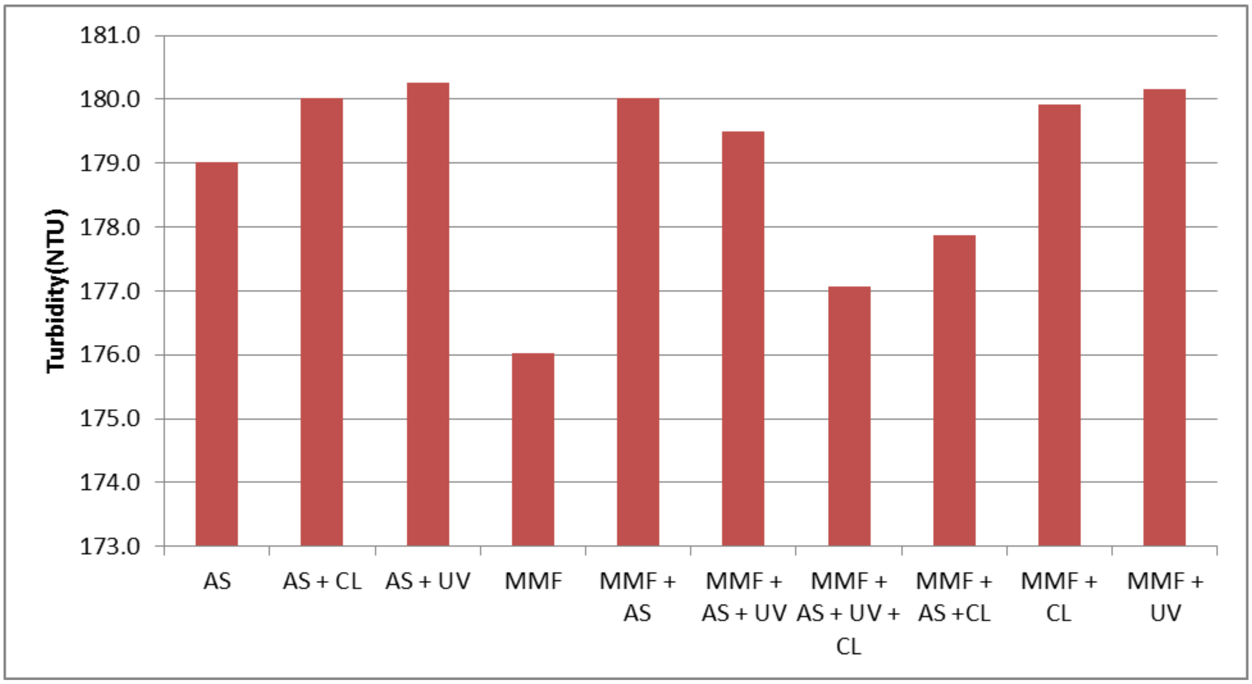

Figure 5. 8: Turbidity of grey water after the treatment process using various treatment combinations

Figure 5.9 below indicates conductivity of grey water after the treatment process using various treatment combinations. The highest conductivity of 279.8 mS/m was achieved when grey water was treated using a combination of MMF and CL. However, the lowest conductivity average of 270.8mS/m was observed when grey water was treated using a combination of MMF, AS and CL. It was also noticed that after each treatment process using various combinations as shown in Figure 5.9, the conductivity of treated grey water was considerably lower than the conductivity of untreated grey water which recorded an average of 444.11mS/m. The conductivity values of grey water after the treatment process using the various combinations in Figure 5.7 were all above National standard and the Department of Water Affairs standard limits of less than 250mS/m.

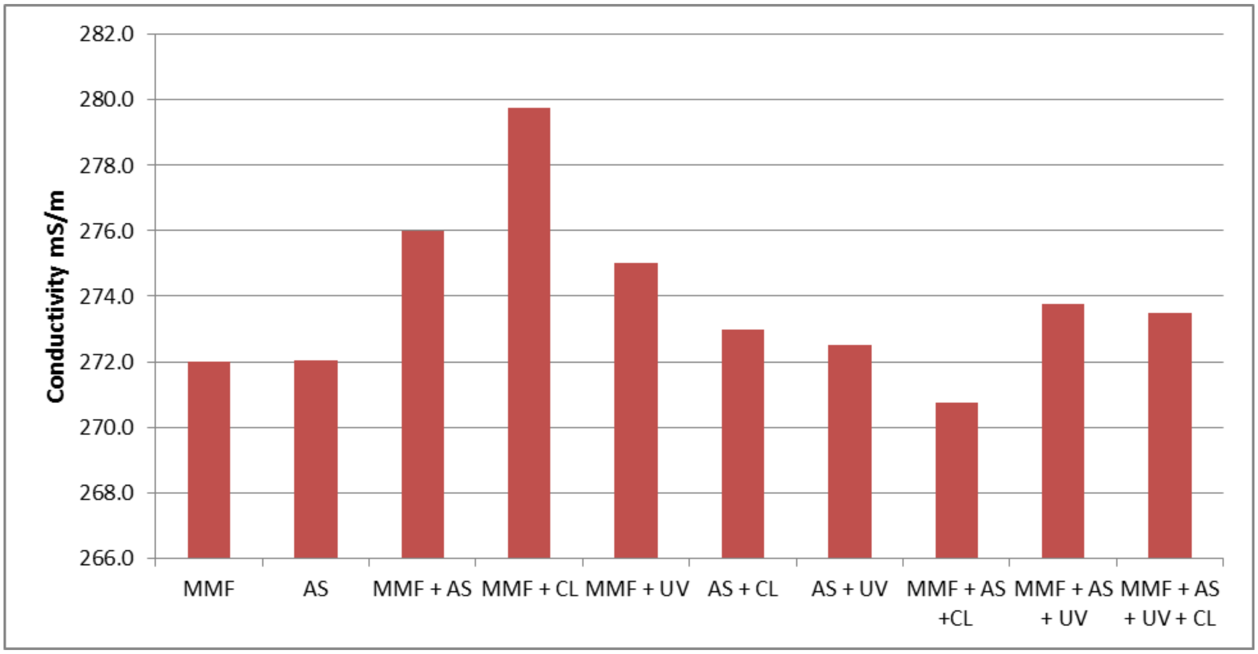

Figure 5. 9: Conductivity of grey water after the treatment process using various treatment combinations

Figure 5.10 below indicates Total Suspended Solids in grey water after the treatment process using various treatment combinations. Figure 5.8 below indicates that the highest average total suspended solids of 83.25mg/L was achieved when grey water was treated using a combination of MMF and AS. However, the lowest total suspended solids average of 80.0mg/L was observed when grey water was treated using a combination of MMF, AS, UV and CL or independently using MMF only. It was also noticed that after each treatment process using the various combination as shown in Figure 5.10, the total suspended solids of treated grey water were considerably lower than the total suspended solids those of untreated grey water which recorded an average of 660.5mg/L. Although the total suspended solids value of water after treatment process using the various combinations in Figure 5.10 were all within the National Standards limits of less than 90.0mg/L, they fell outside the limits of 10 to 25 of the Department of Water Affairs.

Figure 5. 10: Total suspended solids in grey water after the treatment process using various treatment combinations

Table 5.16 below provides a summary of the physical characteristics of treated grey water (which included pH, turbidity, conductivity and total suspended solids) under the different simulated scenarios as discussed above.

Table 5. 16: Physical characteristics of treated grey water under different simulated scenarios

Simulated scenarios	Replication	pH	Turbidity(NTU)	Conductivity(mS/m)	TSS(mg/L)
MMF	9	8.20	176.00	272.00	80.00
MMF + AS	9	9.08	180.01	283.00	83.25
MMF + CL	9	8.77	179.91	279.75	82.00
MMF + UV	9	8.81	180.16	281.00	82.25
AS + CL	9	8.77	180.01	273.00	82.50
AS + UV	9	8.77	180.25	278.50	82.75
MMF + AS +CL	9	8.49	177.88	270.75	81.25
MMF + AS + UV	9	8.85	179.50	273.75	81.00
MMF + AS + UV + CL	9	8.38	177.07	263.50	80.00

5.3.2.2 Discussion of chemical characteristics of treated grey water

Grey water was subjected to individual treatment and combinations treatment of aerobic screening (AS), Multimedia Filtration (MMF), Ultraviolet radiation (UV) and Chlorination (CL) processes. After the above treatment processes were carried out, the chemical characteristics of grey water which included COD, orthophosphate, oil, grease, soap, dissolved iron and manganese were measured in mg/L.

Figure 5.11 below indicates COD in grey water after the treatment process using various treatment combinations. It indicates that the highest COD average of 112 mg/L was achieved when grey water was treated using the combination of MMF and AS or of MMF and UV. However, the lowest COD average of 80.0mg/L was observed when grey water was treated using a combination of either MMF, AS, UV and CL and also independently treating grey water using MMF, AS and CL. It was also noticed that after each treatment process, the COD content of the treated grey water was considerably lower than the COD content of untreated grey water which recorded an average of 565.25 mg/L. The COD values of grey water after applying the various combinations of treatment processes using various combinations in Figure 5.11 were all above the limits of the Department of Water Affairs and National Standards.

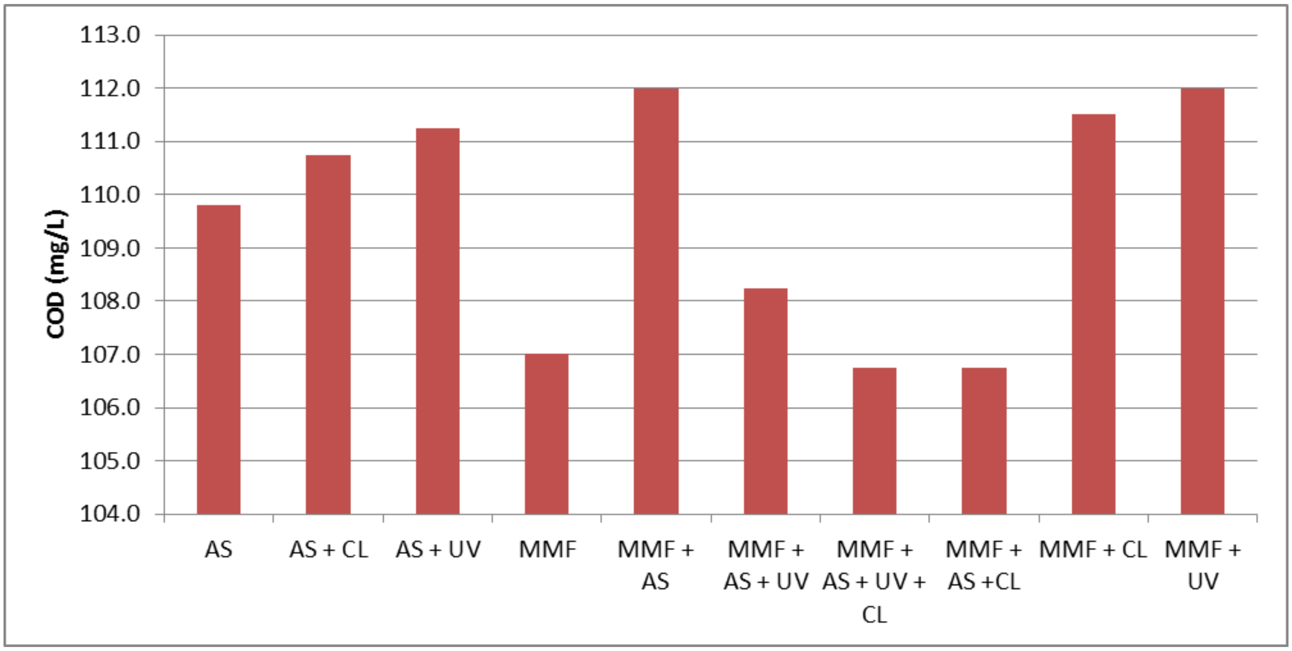

Figure 5. 11: COD content in grey water after the treatment process using various treatment combinations

Figure 5.12 below indicates the orthophosphate in grey water after the treatment process using various treatment combinations. The highest average content of orthophosphate of 0.79 mg/L was achieved when grey water was treated using the independent combination of either MMF and AS, MMF and UV or of MMF and CL (figure 5.12). However, the lowest orthophosphate average of 0.76mg/L was observed when grey water was treated using independent combinations of either MMF, AS and UV, of MMF, AS and CL as well as when treating grey water using MMF only.

It was also observed that after each treatment process, the orthophosphate of treated grey water was considerably lower than the orthophosphate of untreated grey water which recorded an average of 2.28 mg/L.

The orthophosphate values of grey water after treatment process using the various combinations in Figure 5.12 were all within National Standard limits of less than 1.0mg/L. However, none of the total suspended solids values in Figure 5.12 were within the limits of 2.5 and 10 of the Department of Water Affairs.

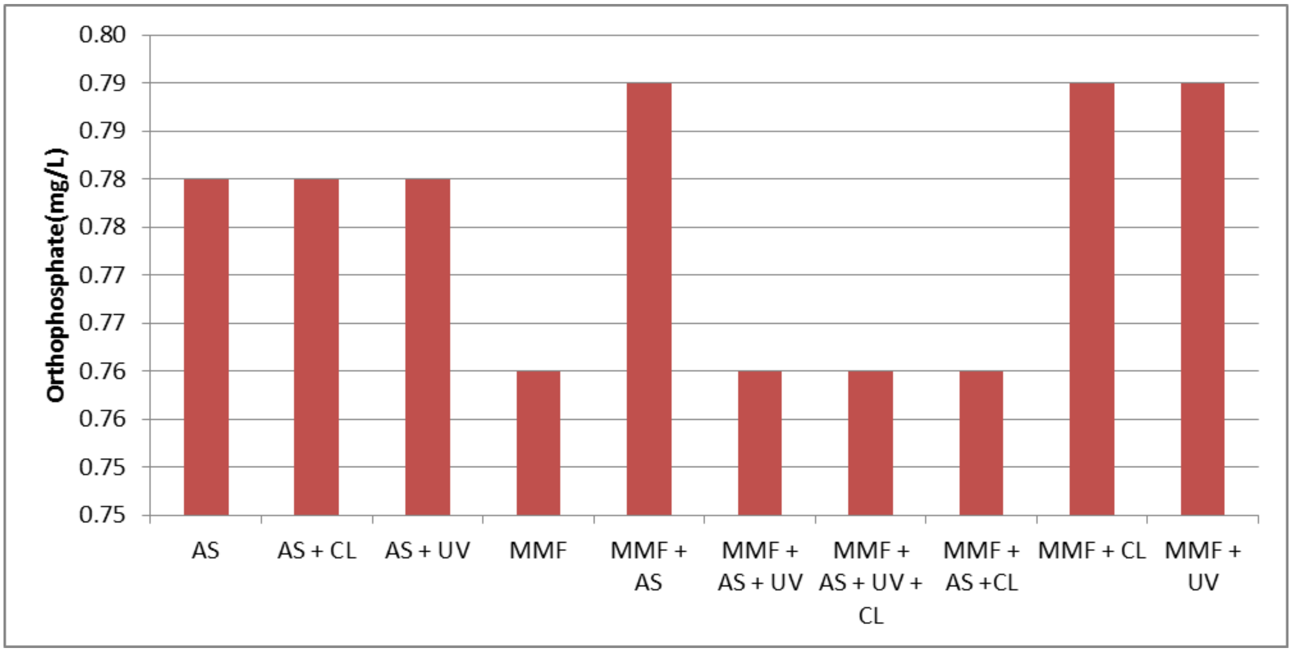

Figure 5. 12: Orthophosphate content in grey water after the treatment process using various treatment combinations

Figure 5.13 below indicates oil, grease and soap content in grey water after the treatment process using the various treatment combinations. It indicates that the highest oil, grease and soap average of 176.5 mg/L was achieved when grey water was treated using a combination of MMF and UV. However, the lowest oil, grease and soap average of 160.08 mg/L was observed when grey water was treated using a combination of MMF, AS, UV and CL.

It was also observed that after each treatment process, oil, grease and soap content of treated grey water was significantly lower than the oil, grease and soap content of untreated grey water which recorded an average of 1271.75 mg/L. The oil, grease and soap values of grey water after treatment process using the various combinations in Figure 5.13 were all above the limits of less 2.5mg/L of the Department of Water Affairs and the National Standard.

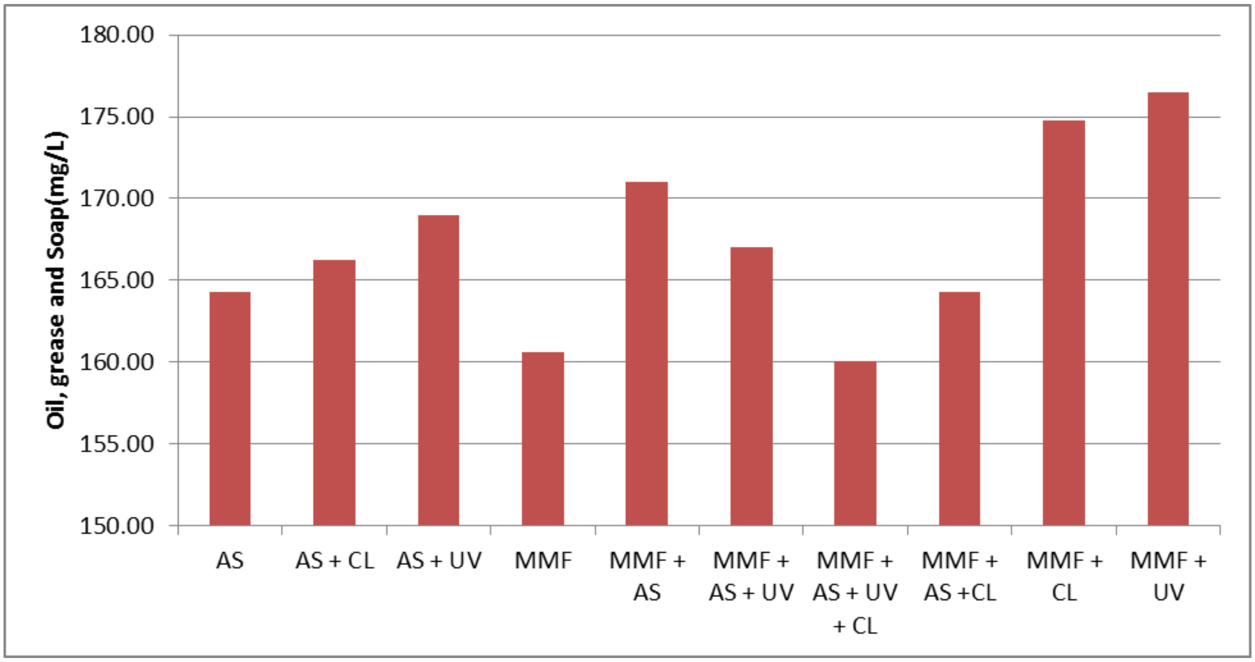

Figure 5. 13: Oil, grease and soap content in grey water after the treatment process using various treatment combinations

Table 5.17 below indicates dissolved iron and manganese in grey water after the treatment process using the various treatment combinations. It indicates that dissolved iron values in all treatment combinations that were used were all below 0.3 mg/L while dissolved manganese values in all treatment combinations were below 0.2 mg/L.

The dissolved iron and manganese values of grey water after treatment process using the various combinations were all within the National Standards and the Department of Water Affairs limits of less than 0.3mg/L and less than 0.2mg/L respectively.

Table 5. 17: Dissolved iron and manganese in grey water after the treatment process using various treatment combinations

Simulated Scenarios	Dissolved Iron	Dissolved Manganese
MMF	< 0.30	<0.20
AS	< 0.30	<0.20
MMF + AS	< 0.30	<0.20
MMF + CL	< 0.30	<0.20
MMF + UV	< 0.30	<0.20
AS + CL	< 0.30	<0.20
AS + UV	< 0.30	<0.20
MMF + AS +CL	< 0.30	<0.20
MMF + AS + UV	< 0.30	<0.20
MMF + AS + UV + CL	< 0.30	<0.20

Table 5.18 below provides a summary of chemical characteristics of treated grey water (which included COD, orthophosphate, oil, grease and soap, iron and manganese) under different simulated scenarios as discussed above.

Table 5. 18: Chemical characteristics of treated grey water under different simulated scenarios

Simulated scenarios	Replication	COD (mg/L)	Orthophosphate (mg/L)	Oil, Grease, Soap (mg/L)	Iron	Manganese
AS	9	109.81	0.78	164.25	< 0.30	<0.20
AS + CL	9	110.75	0.78	166.25	< 0.30	<0.20
AS + UV	9	111.25	0.78	169.00	< 0.30	<0.20
MMF	9	107.02	0.76	160.58	< 0.30	<0.20
MMF + AS	9	112.00	0.79	171.00	< 0.30	<0.20

MMF + AS + UV	9	108.25	0.76	167.00	< 0.30	<0.20
MMF + AS + UV + CL	9	106.75	0.76	160.08	< 0.30	<0.20
MMF + AS +CL	9	106.75	0.76	164.25	< 0.30	<0.20
MMF + CL	9	111.50	0.79	174.75	< 0.30	<0.20
MMF + UV	9	112.00	0.79	176.50	< 0.30	<0.20

5.3.2.3 Discussion of operational alert characteristics of treated grey water according to area of source within Witbank

Table 5.19 shows the operational alert characteristics of treated grey water under various treatment combinations. In order to obtain credible results, each parameter was replicated 9 times. The lowest aluminium content of 0.02 mg/L was achieved (from MMF, AS + CL, MMF + AS +CL, MMF + AS + UV and MMF + AS + UV + CL treatment combinations). The remaining treatment combinations recorded a maximum aluminium content of 0.03mg/L. The aluminium content achieved from all the treatment combinations in Table 5.19 were within the National Standards limit of less than 20mg/L.

Table 5.19 indicates that the maximum calcium content of 16mg/L in treated grey water was recorded from the MMF and AS and the MMF and UV treatment combination respectively, while a minimum calcium content of 13.5mg/L was achieved from the MMF, AS and CL treatment combination. The spread of data values for calcium was low with a standard deviation of about 6.4% of the mean. The maximum chloride content value in treated grey water of 156.5mg/L was recorded from the MMF and UV treatment combinations while a minimum chloride content of 152.0 was recorded (from MMF + AS treatment combination). The chloride content values achieved from all the treatment combinations presented in Table 5.19 were within the National Standards limits of 100 and 350 mg/L. It was also observed that the spread of chloride data values obtained from the various treatment combinations was very low with a very low standard deviation of about 0.9% of the mean.

The maximum potassium content of treated grey water of 0.6mg/L was recorded from the MMF and AS treatment combination while a minimum potassium content of 0.3mg/L was achieved from the MMF treatment and the treatment combinations of MMF and CL as well as of AS and UV. The potassium content values obtained from all treatment combinations presented in Table 5.19 were within the National Standards limits of less than 50mg/L.

Table 5.19 indicates that the maximum sulphate content of 283.25mg/L in treated grey water was recorded from the MMF and AS treatment combination while a minimum sulphate content of 277.5mg/L was achieved from the AS and UV treatment combination. It was also observed that the sulphate content values from all treatment the combinations presented in Table 5.19 were within the National Standards limits of less than 1000 mg/L. On the other hand, the maximum sodium content in treated grey water of 191.75mg/L was recorded from the AS and the MMF and AS treatment combinations while a minimum sodium content of 277.5mg/L was achieved from the AS and UV treatment combinations as presented in Table 5.19. It was also observed that the sodium content values obtained from all the treatment combinations were within the National Standard limits of between 70 and 460mg/L.

Table 5. 19: Operational alert characteristics of treated grey water from Witbank

Simulated Scenarios	Replication	Aluminium	Alkalinity	Calcium	Chloride	Potassium	Sulphate	Sodium
MMF	9	0.02	189.00	15.00	152.09	0.30	279.52	189.06
AS	9	0.03	190.00	15.87	153.05	0.50	280.16	191.75
MMF + AS	9	0.03	189.00	16.00	152.00	0.60	283.25	191.75
MMF + CL	9	0.03	189.74	15.75	155.50	0.30	283.00	188.67
MMF + UV	9	0.03	190.50	16.00	156.50	0.50	281.25	190.00
AS + CL	9	0.02	196.00	14.25	154.25	0.40	279.00	189.75
AS + UV	9	0.03	195.50	15.50	154.25	0.30	277.50	189.25
MMF + AS +CL	9	0.02	199.75	13.50	153.25	0.60	278.25	189.25
MMF + AS + UV	9	0.02	192.50	14.25	153.50	0.40	282.75	190.75

MMF + AS + UV + CL	9	0.02	189.75	13.75	153.50	0.50	283.00	190.89
Maximum value		0.03	199.75	16.00	156.50	0.60	283.25	191.75
Minimum value		0.02	189.00	13.50	152.00	0.30	277.50	188.67
DWA standard			20-100		100.00			
National standard		< 20			100-350	< 50	< 1000	70-460

5.3.2.3 Discussion of resource content in treated grey water

Table 5.20 below indicates the resource content in grey water after exposure to various treatment combinations. A nitrate maximum value of 1.86mg/L was achieved when grey water was subjected to a MMF and AS treatment combination while a minimum value of 1.79mg/L was achieved when grey water was subjected to a MMF, AS, UV and CL treatment combination. The nitrate content values obtained from all treatment combinations demonstrated in Table 5.20 were within the limits of between 1.5mg/l and 15mg/L Department of Water Affairs. However, these values were outside the National Standards limits of less than 1.50mg/L.

It was observed in Table 5.20 that the nitrate values recorded after each of the treatment combinations remained constant at 0.014mg/L. These values for nitrate content in grey water were much lower than the limits between 1.5mg/L and 16mg/L of both the Department of Water Affairs and National Standards. The maximum ammonium content in grey water of 0.31mg/L was recorded when grey water was subjected to the MMF and AS and the MMF and UV treatment combinations. A minimum ammonium content of 0.25mg/L was achieved when grey water was subjected to individual treatment using MMF, or AS, or to a treatment combination of either MMF, AS and CL, or MMF, AS, UV and CL as shown in Table 5.20. The ammonium content values recorded after treatment process using the various treatment combinations were within the National Standards limits of less than 1.0mg/L. However, these values were outside limits of between 2.0mg/l and 3.0mg/L of the Department of Water Affairs

A maximum of 9.75mg/L nitrogen content was recorded when grey water was subjected to an AS and UV treatment combination process. However, a minimum of 8.75mg/L nitrogen content was recorded when grey water was subjected to either MMF process or the treatment combination, of either, MMF, AS, and CL or of MMF, AS, UV and CL. The nitrogen content values recorded after various treatment combinations were all within the Department of Water Affairs limit of between 1.5mg/L and 15mg/L but outside the National Standards limits of less than 5mg/L. Finally, the maximum phosphorus content of 1.16mg/L was recorded when grey water was subjected to the MMF + AS treatment combination while a minimum of 1.02mg/L was recorded when grey water was subjected to a MMF process only or a, and MMF, AS, UV and CL treatment combination. The phosphorus content values recorded after the various treatment combinations were all outside the limits of the Department of Water Affairs and National Standards.

Table 5. 20: Resource content in grey water after exposure to various treatment combinations

Simulated Scenarios	Replication	Nitrate	Nitrite	Ammonia	Nitrogen	Phosphorus
MMF	9	1.8	0.014	0.25	8.25	1.02
AS	9	1.82	0.014	0.25	8.75	1.06
MMF + AS	9	1.86	0.014	0.31	9.5	1.16
MMF + CL	9	1.85	0.014	0.3	8.5	1.12
MMF + UV	9	1.84	0.014	0.31	9.5	1.15
AS + CL	9	1.83	0.014	0.3	8.75	1.08
AS + UV	9	1.84	0.014	0.3	9.75	1.08
MMF + AS +CL	9	1.8	0.014	0.25	8.25	1.03
MMF + AS + UV	9	1.8	0.014	0.3	8.75	1.04
MMF + AS + UV + CL	9	1.79	0.014	0.25	8.25	1.02
Maximum		1.86	0.014	0.31	9.75	1.16
Minimum		1.79	0.014	0.25	8.25	1.02
DWA standard		1.5-15	1.5-16	2-3	1.5-15	2.5-10
National standard		< 1.5	1.5-16	< 1.0	< 5.0	< 1.0

5.3.2.4 Discussion of microbiological determinants in treated grey water

Table 5.21 below indicates the microbiological determinants recorded after treatment process of grey water under various treatment combinations. It can be observed that the

Ecoli, total coliform and heterotrophic count were all under 1000 units after treatment processes as shown. These results were within the limits of less than 1000 units of the Department of Water Affairs and National Standard.

Table 5. 21: Microbiological determinants in treated grey water

Simulated Scenarios	Ecoll	Total coliform	Heterotrophic count
MMF	< 1000	< 1000	< 1000
AS	< 1000	< 1000	< 1000
MMF + AS	< 1000	< 1000	< 1000
MMF + CL	< 1000	< 1000	< 1000
MMF + UV	< 1000	< 1000	< 1000
AS + CL	< 1000	< 1000	< 1000
AS + UV	< 1000	< 1000	< 1000
MMF + AS +CL	< 1000	< 1000	< 1000
MMF + AS + UV	< 1000	< 1000	< 1000
MMF + AS + UV + CL	< 1000	< 1000	< 1000

5.4 Summary findings and conclusion

It was observed that grey water production is depended on volume of water consumed and income levels of inhabitants. Furthermore, the amount of grey water produced was observed to be influenced by the location of household consumers. The least amount of grey water per given volume was produced by the townships while the central areas produced the most amount of grey water per given volume. Whereas untreated grey water from the central areas of Witbank had the highest ammonium, nitrate and nitrate content. The untreated grey water from the townships in Witbank had the least ammonium, nitrate and nitrite contents. Nitrites, ammonium and nitrates content that were outside the Department of Water Affairs standards.

The results of the test on untreated grey water indicated that untreated grey water in Witbank is acidic and that the total suspended solids; turbidity and conductivity of untreated grey water within the city were also high and outside the specifications of the Department of Water Affairs and National Standards. It was found that untreated grey water from Witbank recorded low orthophosphate, low dissolved iron, and manganese levels that were within the ranges of the Department of Water Affairs and National Standard. However, COD, oil, grease and soap content in untreated grey water from Witbank were very high and outside the specifications of the Department of Water Affairs and National Standard.

Sulphate, sodium, chloride, E coli, total coliforms (per 100ml) and heterotrophic plate count contents in untreated grey water from the city of Witbank were also high and outside the limits of the Department of Water Affairs limits. However, aluminium and potassium content in untreated grey water were low and within National Standard values.

Grey water was treated using simulated treatment combinations of Aerobic Screening (AS), Multimedia Filtration (MMF), Ultraviolet radiation (UV) and Chlorination (CL) processes. It was observed that the lowest pH of 8.02, lowest turbidity, low conductivity, and lowest total suspended material, and lowest orthophosphate content were achieved after treatment with MMF. The pH, turbidity, conductivity and total suspended values after treatment with MMF were all within the standard limits of the Department of Water Affairs. On the other hand, the lowest COD, and lowest oil, grease and soap content were achieved when grey water was treated with combination of MMF, AS, UV and CL. Despite this, the COD content and oil, grease and soap content were second best after treatment with MMF only.

Maximum calcium content was achieved when grey water was subjected to either MMF and AS or MMF and UV while maximum potassium content was achieved when grey water was treated with the combination of MMF and AS or MMF, AS and CL. On the other hand, maximum chloride content was recorded when grey water was subjected to either MMF and UV or MMF and CL. Finally, maximum sulphate and sodium contents were achieved when grey water was subjected to MMF and AS.

It was also observed that nitrogen and nitrate content values recorded after various treatment combinations were applied were all within the specifications of the Department of Water Affairs whereas nitrite, ammonium and phosphorus were outside the specifications of the Department of Water Affairs. Ecoli, total coliform and heterotrophic counts were all under 1000 units after various treatment processes and were within the limits of less than 1000 units of the Department of Water Affairs and National Standards.

Based on the results of this study it can be concluded that the MMF treatment process produced the best results in terms, of physical and chemical characteristics as well as the microbiological determinants of grey water. However, the MMF and AS, MMF and UV and the MMF, AS and CL treatment processes produced the best results in terms of resource contents in grey water. Seeing that the MMF treatment process is efficient, cost effective and feasible to put into practice, it should be considered for treatment of grey water.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

South Africa has been found to experience challenges with availability of fresh water. This is partly due to low and variable annual rainfall along with high natural evaporation levels. The high and growing demand for water coupled with poor use of existing water resources add to the pressure on fresh water availability. It is believed that if grey water is recycled appropriately, it becomes a significant source of water that could potentially cover for the lack of fresh water and can be a source of resources such as nitrogen, potassium and phosphorus. Before recycled grey water can be of any use, it is important to assess its quality before and after the treatment process.

An experimental study was therefore carried out in a South African city (Witbank in Mpumalanga Province) with the aim of examining the perspectives of grey water recycling through comprehension of the quality (impurities and nutrient content) of grey water generated in the study area and quantifying the availability of different resources such as nitrogen, potassium and phosphorus, which were recovered from grey water.

Furthermore, a grey water survey in the form of a standardised questionnaire was conducted in Witbank to assess water consumption, grey water production and income profiles per household across various locations such as the upscale, central, township and City areas of Witbank. This chapter therefore, presents conclusions, recommendations and the scope for further research on grey water recycling and resource recovery.

6.2 Conclusion

In line with the approach of the study, the conclusions of the study on grey water recycling and resource recovery in Witbank City are subdivided into experimental results and survey results respectively.

6.2.1 Conclusion from experimental study results

Based on the experimental results of the study conducted in the city Witbank in Mpumalanga Province with the aim of examining the quality of grey water and quantifying the availability of different resources in grey water such as nitrogen, potassium and phosphorus, it can be concluded that;

- The pH of untreated grey water from the study area was slightly acidic at 6.92 and was within range of the national standard set by the Department of Water Affairs. However, the turbidity, total suspended solids and conductivity of untreated grey water were generally high and outside the Department of Water Affairs and National Standards Specifications.

- The highest average pH of 9.08 was achieved when grey water was treated using a combination of MMF and AS while the lowest average pH of 8.20 was accomplished when grey water was treated using MMF only. Treating grey water with a combination of MMF, AS and UV also significantly increased its pH to 8.85.

- It was discovered that generally the turbidity, conductivity and total suspended solids in untreated grey water were high and outside the Department of Water Affairs and National Standards specifications.

- Untreated grey water from the central areas of Witbank was more turbid recording a mean of 613.5 NTU while grey water from the townships in Witbank had the least turbidity of an average of 586.5 NTU. Grey water from upscale developments and city areas recorded almost similar averages of 602.7 and 606.4 NTU respectively. Conductivity of the untreated grey water followed a similar pattern as above. Untreated grey water from the central areas recorded the highest mean conductivity of 459.5 mS/m while grey water from the townships had the least conductivity of 419.8 mS/m. Grey water sourced from the central areas of Witbank had the highest total suspended material content with a mean of 661.5 mg/L while grey water from the city followed closely with an average of 660.5 mg/L. Grey water from Witbank townships had the least total suspended material content.

- The highest average turbidity of 180.25 NTU was achieved when grey water was treated using a combination of AS and UV while the lowest average turbidity of 176.03 NTU was achieved when grey water was subjected to the multimedia filtration process only. It was also observed that grey water treated with a combination of MMF and UV recorded a high average turbidity of 180.06 NTU.

- The highest conductivity of 279.8 mS/m was achieved when grey water was treated using a combination of MMF and CL. However, the lowest conductivity average of 270.8mS/m was observed when grey water was treated using a combination of MMF, AS and CL.

- The highest average total suspended solids content of 83.25mg/L was achieved when grey water was treated using a combination of MMF and AS. However, the lowest total suspended solids average of 80.0mg/L was observed when grey water was treated using a combination of MMF, AS, UV and CL and also when treated independently using MMF only. However, none of the total suspended solids values were within the standard limits of 10 and 25 of the Department of Water Affairs.

- The average COD, orthophosphate, oil, grease, and soap contents of untreated grey water were high and above the standard ranges specified by the Department of Water Affairs and National Standards. However, untreated grey water recorded low dissolved iron and manganese content that were within the limits of the Department of Water Affairs and National Standard.

- Oil, grease and soap content in untreated grey water was heaviest in the central areas of Witbank with an average of 1284.3 mg/L and was followed closely by the city areas that recorded an average of 1271.8mg/L. Of all the Witbank areas investigated in this study, the townships again recorded the least amount of oil, grease and soap content in untreated grey water. Similarly, the central areas had the highest orthophosphate content followed by the city areas. Untreated grey water from the upscale development areas and townships had the lowest orthophosphate content of about 2.2mg/L.

- The highest average COD content of 112 mg/L was achieved when grey water was treated using an independent combination of MMF and AS or MMF and UV. However, the lowest average COD content of 80.0mg/L was observed when grey water was treated using a combination of MMF, AS, UV and CL and also when independently treating grey water using MMF, AS and CL.

- The highest average orthophosphate content of 0.79 mg/L was achieved when grey water was treated using an independent combination of MMF and AS, MMF and UV or MMF and CL as shown in figure 5.12. However, the lowest orthophosphate average of 0.76mg/L was observed when grey water was treated using independent combinations of MMF, AS and UV, or MMF, AS and CL, or using MMF only.

- The highest average oil, grease and soap content of 176.5 mg/L was achieved when grey water was treated using the treatment combination of MMF and UV. However, the lowest average oil, grease and soap content of 160.08 mg/L was observed when grey water was treated using a combination of MMF, AS, UV and CL.

- Chloride levels, as well as sulphate and sodium content in untreated grey water were high and outside the maximum values stipulated by the Department of Water Affairs and National Standards. Despite this, the aluminium and potassium content in untreated grey water were low and within specifications of the Department of Water Affairs and National Standards.

- Of all the areas investigated in the study, the untreated grey water from the central areas of Witbank had the highest chloride, sulphate and sodium contents followed by the city areas. Whereas, untreated grey water from the townships had the least chloride, sulphate and sodium contents.

- The highest calcium content in treated grey water of 16mg/L was recorded from the MMF and AS - as well as the MMF and UV treatment combination while a minimum calcium content of 13.5mg/L was achieved when grey water was treated using a combination of MMF, AS and CL.

- The highest chloride content of 156.5mg/L was recorded when grey water was treated using a combination of MMF and UV while the lowest chloride content of 152.0mg/L was recorded after a treatment combination of MMF and AS was used.

- The highest potassium content of 0.6mg/L was recorded when grey water was treated using a combination of MMF and AS while the lowest potassium content of 0.3mg/L was achieved when treatment combination of MMF, MMF and CL or AS and UV was used.

- The highest sulphate content in treated grey water of 283.25mg/L was recorded after a treatment combination of MMF and AS treatment was used while the treatment combination of AS and UV recorded the lowest sulphate content of 277.5mg/L. It was also observed that the sulphate content values obtained from all the treatment combinations that were used were within the National Standard limits of less than 1000 mg/L.

- The highest sodium content of 191.75mg/L was recorded after treating the grey water using AS only or using a combination of MMF and AS while the lowest sodium content of 277.5mg/L was achieved using a AS and UV treatment combination.

- Untreated grey water generally recorded high nitrate and phosphorus contents which were within the specifications of the Department of Water Affairs but fell outside the National Standard range. However, the nitrites content in untreated grey water sourced from Witbank was lower than the lower bounds of the Department of Water Affairs and National Standards. Similarly, the ammonium content in untreated grey water was lower than the lower bounds of the Department of Water Affairs but within the National Standards range of less than 1.0 mg/L. On the other hand, the nitrogen content in untreated grey water was high recording an average way higher than the upper bounds of the Department of Water Affairs and the National Standards.

- The highest ammonium, nitrate and nitrite content were recorded in the untreated grey water from the central areas of Witbank and the second highest in the untreated grey water from the city areas of Witbank. However, untreated grey water from townships in Witbank had the lowest ammonium, nitrate and nitrite amounts.

- The highest nitrate highest value of 1.86mg/L was achieved when grey water was subjected to a MMF and AS treatment combination while the lowest value of 1.79mg/L was achieved when grey water was subjected to a MMF, AS, UV and CL treatment combination.

- The highest ammonium content in grey water of 0.31mg/L was recorded when grey water was subjected to a treatment combination of either MMF and AS or MMF and UV treatment combinations while a lowest ammonium content of 0.25mg/L was achieved when grey water was subjected to treatment using either

MMF, or AS, or a treatment combination of either MMF, AS, and CL, or MMF, AS, UV and CL.

- A maximum nitrogen content of 9.75mg/L was recorded when grey water was subjected to the AS and UV treatment combination. However, a minimum of 8.75mg/L nitrogen content was recorded when grey water was subjected to a MMF treatment only or treatment combination of either, MMF, AS and CL or MMF, AS, UV and CL.

- Microbiological determinants such as E coli, total coliforms and heterotrophic plate count in untreated grey water were high and well above the range of the Department of Water Affairs and the National Standards.

- It was observed that the Ecoli, total coliform and heterotrophic count were all under 1000 units after treatment processes.

- The physical, chemical, operational alert and resources content as well as microbiological characteristics of grey water after each treatment process combination was observed to be either less than or within the lower bounds of the department of water affairs Standard stipulations.

6.2.2 Conclusion from survey study results

Based on the result of the household survey that was conducted in Witbank, it can be concluded that:

- Water consumption of the upscale development areas was the highest at an average of 122.5 litres per household per day and an average income of R88, 875 a month. Consequently, the upscale development areas also produced the highest amount of grey water of 93.1litres per day. The second highest average daily water consumption of 76.3 litres was recorded in the central areas that produced an average of 58.1 litres grey water per day. Households in the central areas earned an average income of R22, 250 a month. On the other hand, the lowest water consumption of 52.5 litres per household per day was recorded in the townships while the City dwellers were second from the bottom consuming an average of 56.3 litres per household per day. City dwellers had the lowest average income of R5 313 per month compared to township dwellers who earned an average of R6, 125 per month.

- The association between income and grey water production was tested using the Chi- Squared Test and the data collected from households in Witbank. It was discovered that there was a significant positive ($p < 0.05$), correlation between income and water consumption. There was also a significant positive ($p < 0.05$), correlation between income and grey water production.

- Regression analyses showed that there was a linear and significant causal correlation (R^2 of 71.9%) between income and household water demand where income was an independent variable while water demands a dependent variable. Similarly, a linear and significant correlation (R^2 of about 72%) between income and household grey water production was observed.

- Based on the Analysis of Variance results, it was dicovered that the mean income across locations in Witbank (upscale development, city, township and central areas) differ significantly ($p < 0.01$). Likewise, the means recorded for water usage per capita, household water consumption and grey water production across these locations were significantly ($p < 0.05$) different. However, there was no statistical evidence to suggest any significant ($p > 0.05$) differences in percentage of grey water production across locations.

- Pairwise comparison of group means to determine if there were any significant differences across locations (pairwise) on income, household water consumption and grey water production, was performed using the t-test. It was discovered that mean income of any combination of locations (upscale development, city, townships and central areas) differed significantly ($p < 0.01$). In the same manner, the mean water usage per capita, household water consumption and grey water production across any cobination of locations in Witbank differed significantly ($p < 0.05$). However, there was no statistical evidence to suggest any significant ($p > 0.05$) differences in percentage of grey water production across locations.

The results indicated that untreated grey water in Witbank is acidic and that the total suspended solids, turbidity and conductivity of untreated grey water within the city were also high and outside the ranges of the Department of Water Affairs and National Standards. It was found that untreated grey water from Witbank recorded low orthophosphate, dissolved iron and manganese levels that were within the ranges of the Department of Water Affairs and National Standard. However, COD, oil, grease and soap contents in untreated grey water from Witbank were very high and outside the limits of the Department of Water Affairs and National Standards.

Sulphate, sodium, chloride, E coli, total coliforms (per 100ml) and heterotrophic plate count contents in untreated grey water from the city of Witbank were also high and outside the limits of the Department of Water Affairs. However, aluminium and potassium content in untreated grey water were low and within National Standards values.

Grey water was treated using simulated treatment combinations of Aerobic Screening (AS), Multimedia Filtration (MMF), Ultraviolet radiation (UV) and Chlorination (CL) processes.

It was observed that the lowest pH, turbidity, conductivity, total suspended material, and lowest orthophosphate values were achieved after treatment with MMF. The pH, turbidity, conductivity and total suspended values after treatment with MMF were all within the standard limits of the Department of Water Affairs. On the other hand, lowest COD, oil, grease and soap contents were achieved when grey water was treated using a combination of MMF, AS, UV and CL. Despite this, the COD content and oil, grease and soap were second best after treatment with MMF only.

The maximum calcium content was achieved when grey water was subjected to either MMF and AS or MMF and UV treatments, while maximum potassium content was achieved when grey water was treated with a combination of either MMF and AS or MMF, AS and CL. On the other hand, maximum chloride content was recorded when grey water was subjected to either MMF and UV or MMF and CL treatment combination.

It was observed that nitrogen and nitrate content values after various treatment combinations were all within the specifications of Department of Water Affairs while nitrite, ammonium and phosphorus were outside specifications of the Department of Water Affairs. The Ecoli, total coliform and heterotrophic count were all under 1000 units after various treatment processes and were within the limits of less than 1000 units of the Department of Water Affairs and National Standard.

Based on the results it was observed that the best results in terms of physical and chemical characteristics of grey water as well as the microbiological determinants of grey water were obtained after MMF treatment processes were used. However, the MMF and AS; MMF and UV as well as the MMF, AS and CL treatment combinations produced the best results in terms of resource contents in grey water. All these treatment processes produced results that were within specifications of the Department of Water Affairs and National Standard. This showed that it is feasible to recycle grey water for domestic purposes.

6.3 Recommendations

Based on the above mentioned findings and conclusion, the following recommendations can be taken into account for implementation by the eMalahleni Municipality in order to improve the water situation;

- Recycled grey water is a demand management option that can be implemented within a community to reduce reliance on main water supply for non-potable uses like flushing and gardening.

- Since it has been proven in the laboratory that it is possible to recycle grey water to acceptable standards of the Department of Water Affairs and National Standards, more support from various stakeholders is needed to run this idea on a large scale. The government in particular can make financial resources available as a first step to cover the high costs associated with construction, operation and maintenance of the system.

- In order to get potable water, grey water should be subjected to MMF as this treatment process produced the best results in terms of physical, chemical and microbiological characteristics of treated grey water. It is an efficient and cost effective process that produced the desired results that meet the specifications of the Department of Water Affairs and National Standard.

- However, in order to recover resources in grey water, the individual treatment combination of either MMF and AS; MMF and UV or MMF, AS and CL recommended as these treatment processes produced the best results out of all the other simulated combinations that were used in the study.

- The government should formulate and implement water management policies that deliberately and visibly promote the use of recycled water within communities

- An aggressive awareness programme needs to be implemented to ensure that household water consumers understand the initiative of recycling water as suggested in this study. This will help to get a buy in from water consumers and reduce the risks of poor acceptance of the initiative.

- Strategic marketing can be used to promote grey water recycling. Incentives such as tax deductions and rebates can be used to entice consumers with little or no interest in sustainable water use and management.

- An effective water saving strategy needs to be formulated and implemented prioritising the household of upscale development and central areas of the city that are high earners and high consumers of large volumes of water.

6.4 Limitations of the study

- The survey conducted was based on a limited sample size because of unavailability and lack of willingness of citizens to participate in the survey as well as the time limitation on the completion of the research.

- The experimental study conducted was also based on a limited number of samples due to limited availability of resources in terms of time and funding.

- The examination of technologies for recovery of the chemical resources such as Nitrogen, Phosphorus and Potassium was kept out of the scope of the study.

6.5 Scope for further study

The following suggestions are made for further research:

- A similar study needs to be undertaken, but this time covering other areas or communities with different environments in order to get further tests on recycling of water,

- A grey water recycling scheme for agricultural irrigation should be developed with consideration of the economic feasibility of the treatment method,

- A thorough investigation needs to be undertaken focusing on the behavioural attitudes of water consumers and acceptance of the use of recycled water.

- Also, since the quality of grey water differs according to type of consumption in different cities, further studies by considering other cities are necessary for generalisation of the findings.

- Since, the examination of technologies for recovery of these chemical resources was kept out of the scope of this study, further studies in this regard are essential.

6.6 Concluding remarks and contribution of study

This study was conducted by treating grey water collected from domestic users' bathrooms, showers, kitchens and laundry in the city of Witbank. Data for the study was collected through experimentation and a survey questionnaire. On the one hand, the survey questionnaire results showed that grey water production is depended on volume of water consumed and income levels of inhabitants and on the other hand, the results indicated that the amount of grey water produced is influenced by the location of household consumers. Townships produced the least amount of grey water per given volume while the central, upscale and city areas (in that order) of Witbank produced more of grey water than the townships.

Experimental results showed that untreated grey water in Witbank is acidic and that the total suspended solids, turbidity and conductivity of untreated grey water within the city is also high and outside the standards of the Department of Water Affairs and National Standards.

The results from experimental investigation also showed that the untreated grey water of Witbank has low orthophosphate, dissolved iron, and manganese levels that are within the range of the Department of Water Affairs and National Standard. However, it was established that untreated grey water from the city of Witbank has a high COD, oil, grease and soap content that is outside the specifications of the Department of Water Affairs and National Standard. Likewise, sulphate, sodium, chloride E-coli, total coliforms (per 100ml) and heterotrophic plate count contents in untreated grey water from the city were found to be high and outside the limits of the Department of Water Affairs. However, aluminum and potassium content in untreated grey water were low and within National standard values.

Grey water was treated using simulated treatment combinations of Aerobic Screening (AS), Multimedia Filtration (MMF), Ultraviolet radiation (UV) and Chlorination (CL) processes. It was established that the lowest pH, turbidity, conductivity, total suspended material, and orthophosphate were achieved when grey water was subjected to the MMF treatment process. The pH, turbidity, conductivity and total suspended values after treatment with MMF were all within the standards of the Department of Water Affairs. On the other hand, the lowest COD, and oil, grease and soap contents were achieved when grey water was treated with a combination of MMF, AS, UV and CL. Despite this, the COD content and oil, grease and soap content results were second best after subjecting grey water to MMF treatment process.

Maximum calcium content was achieved when grey water was subjected to either MMF and AS or MMF and UV while maximum potassium content was achieved when grey water was treated with MMF and AS or with MMF, AS and CL. On the other hand, maximum chloride content was recorded when grey water was subjected to either MMF and UV or MMF and CL while maximum sulphate and sodium contents were achieved when grey water was subjected to MMF and AS.

The experimental investigation indicated that after various treatment combinations the nitrogen and nitrate content values were all within the limits of the Department of Water Affairs while nitrite, ammonium and phosphorus contents were outside the limits of the Department of Water Affairs. E-coli, total coliform and heterotrophic count were all under 1000 units after various treatment processes were applied. The results on all microbiological determinants after various treatment processes were within the limits of less than 1000 units of the Department of Water Affairs and National Standards.

In summary the results of the investigation showed that in comparison to the other treatment combinations, the MMF treatment process produces the best results in terms, of physical and chemical characteristics of grey water as well as the microbiological determinants of grey water. However, the MMF and AS, the MMF and UV and the MMF, AS and CL treatment processes produce the best results in terms of resource contents in grey water. Therefore, MMF treatment process should be considered above the MMF and AS, the MMF and UV or the MMF, AS and CL treatment processes to treat grey water as it is efficient, cost effective and is feasible to put into practice.

This investigation uncovered that amongst all available treatment combinations that were tested in the study, the MMF treatment process is an appropriate method of recycling grey water that is collected from domestic users. The MMF treatment process provides not only good physical and chemical characteristics of grey water, but also microbiological determinants that meet the specifications of the Department of Water Affairs and National Standards. Even though the MMF treatment process is not the best method in the recovery of resources such as nitrates, nitrites, ammonium, nitrogen and phosphorus, the method recovers significant amounts of nitrates, nitrogen and phosphorus that are within specifications of the Department of Water Affairs and National Standards. In Addition, the MMF treatment process is cost effective, efficient and is feasible to put into practice to benefit domestic water users.

However, further investigations by considering other cities are necessary to generalize the findings of this study.

The new contribution

The benefit of the effective recycling of grey water using the MMF treatment process is that it ensures availability of water when required. As grey water is not quite affected by climate, the process minimises the pressure on potable water demand. It minimises the volume of waste water entering sewers and on site treatment systems, resulting in lower energy requirements for pumping water and reducing the load on sewer infrastructure by prolonging its life and delaying the requirement of significant capital for renovations or expansion. Consequently, water bills for domestic users can be significantly reduced. Effective recycling of grey water using the MMF treatment process also helps to recover resources in the grey water that can be used for various purposes such as fertilizer, and ammonium gas for industrial use. Finally, ensures effective recycling of grey water that a healthy garden is maintained even during periods of drought. Based on the above premise this study contributes in terms of finding appropriate treatment method based on the combination of various treatment processes for the recycling of grey water in the cities of South Africa. It has also shown that grey water constitutes significant quantity of Nitrogen, Phosphorous and Potassium, which offers an opportunity for potential recovery through appropriate processes. The study has practical implications too. Recycling of grey water can supplement to the existing water supply system in order to meet the increasing water demand in the city. Further, nutrients that are wasted in the form of waste water can be recovered.

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Appendix 1: Simulated scenarios under different conditions of experiments

Scenarios	Type of Scenarios	Number of samples	Material used/ chemical	Quantity of grey water/volume of chemical	Conditions of the experiment
S-1	MMF + AS	9	MMF column consisting of approximately 5cm supporting gravel, 10cm quartz sand, 10cm garnet and 7cm anthracite. Aeration machine (which uses gas) but using specifically air for aerobic screening.	500ml of grey water in glass beakers.	During this process, grey water passes into the filter houses where it flows through rapid gravity sand filter beds of finely graded sand and pebbles. The suspended solids are removed during this process. Grey water is again treated using aerobic screening, where oxygenated air is pumped from the aeration machine for 20 minutes. It was observed that this step is a unique odour free process to reduce insoluble material to a negligible residue.

S-2	AS + UV	9	Aeration Machine (which uses gas) but using specifically air for aerobic screening. UV Light	500ml of grey water in glass beakers UV light	Grey water is treated using aerobic screening. Where oxygenated air is pumped from the aeration machine for 20 minutes. It was observed that this step is a unique odour free process to reduce insoluble material to a negligible residue. Grey water is passed through UV light, which acts as barrier providing additional protection against pathogens.

Scenarios	Type of Scenarios	Number of samples	Material used/ chemical	Quantity of grey water/volume of chemical	Conditions of the experiment
S-1	AS + CL	9	Aeration Machine (which uses gas) but using specifically air for aerobic screening	500ml of grey water in glass beakers	Grey water is treated using aerobic screening. Where oxygenated air is pumped from the aeration machine for 20 minutes. It was observed that

			Chlorine (Bleach)	10-500ml was used for each beaker	this step is a unique odour free process to reduce insoluble material to a negligible residue. Chorine residue is added to protect the water against pathogens. This is the only time any chemical has been used throughout the process.
S-2	MMF + UV	9	MMF column consisting of approximately 5cm supporting gravel, 10cm quartz sand, 10cm garnet and 7cm anthracite UV Light	500ml of grey water in glass beakers UV light	During this process, grey water passes into the filter houses where it flows through rapid gravity sand filter beds of finely graded sand and pebbles. The suspended solids are removed during this process. Grey water is passed through UV light, which acts as barrier providing additional protection against pathogens.

Scenarios	Type of Scenarios	Number of samples	Material used/ chemical	Quantity of grey water/volume of chemical	Conditions of the experiment
S-1	MMF + AS + CL	9	MMF column consisting of approximately 5cm supporting gravel, 10cm quartz sand, 10cm garnet and 7cm anthracite. Aeration Machine (which uses gas) but using specifically air for aerobic screening Chlorine (Bleach)	500ml of grey water in glass beakers 10-500ml was used for each beaker	During this process, grey water passes into the filter houses where it flows through rapid gravity sand filter beds of finely graded sand and pebbles. The suspended solids are removed during this process. Grey water is again treated using aerobic screening. Where oxygenated air is pumped from the aeration machine for 20 minutes. It was observed that this step is a unique odour free process to reduce insoluble material to a negligible residue. Chorine residue is added to protect the water against pathogens. This is the only time any chemical has been used throughout the process

S-2	MMF + AS + UV	9	Aeration Machine (which uses gas) but using specifically air for aerobic screening. UV Light	500ml of grey water in glass beakers. UV light	During this process, grey water passes into the filter houses where it flows through rapid gravity sand filter beds of finely graded sand and pebbles. The suspended solids are removed during this process. Grey water is treated using aerobic screening. Where oxygenated air is pumped from the aeration machine for 20 minutes it was observed that this step is a unique odour free process to reduce insoluble material to a negligible residue. Grey water passed through UV light, which acts as barrier providing additional protection against pathogens.

Scenarios	Type of Scenarios	Number of samples	Material used/ chemical	Quantity of grey water/volume of chemical	Conditions of the experiment
S-1	MMF + CL	9	MMF column consisting of approximately 5cm supporting gravel, 10cm quartz sand, 10cm garnet and 7cm anthracite. Chlorine (Bleach)	500ml of grey water in glass beakers 10-500ml was used for each beaker	During this process, grey water passes into the filter houses where it flows through rapid gravity sand filter beds of finely graded sand and pebbles. The suspended solids are removed during this process. Chorine residue is added to protect the water against pathogens. This is the only time any chemical has been used throughout the process
S-2	MMF + AS + UV + CL	9	Aeration Machine (which uses gas) but using specifically air for aerobic screening. UV Light	500ml of grey water in glass beakers 10-500ml was used for each beaker	During this process, grey water passes into the filter houses where it flows through rapid gravity sand filter beds of finely graded sand and pebbles. The suspended solids are removed during this process.

				UV light	Grey water is treated using aerobic screening, where oxygenated air is pumped from the aeration machine for 20 minutes. It was observed that this step is a unique odour free process to reduce insoluble material to a negligible residue. Grey water is passed through UV light, acts as barrier providing additional protection against pathogens. Chorine residue is added to protect the water against pathogens. This is the only time any chemical has been used throughout the process.

Appendix 2: GREY WATER SURVEY QUESTIONNAIRE

Section 1: Bio-data

1. House Number: ____

2. Interviewee's Full Name: ____

3. Gender: ____

4. Age: ____

5. Religion: ☐ Ancestral beliefs ☐ Christianity ☐ Islam ☐ Other (specify): ____________

6. Occupation: ☐ None ☐ Formal ☐ Informal (no regular income)

7. Household Income per month

   ☐ None ☐ R500-1000 ☐ R1000-R5000 ☐ R5000-R10000 ☐ > R10000

8. Number of people in household: ________________________________

9. Number of children, ages: ____________________________________

10. Type of House: ☐ Traditional dwelling ☐ Estate/ stand dwelling ☐ Informal dwelling

11. How long have you lived at the present site: __________________________

Section 2: Water Consumption Patterns

12. Distance from your house to water point:

☐ <10m ☐ 10-50m ☐ 50-100m ☐ 100-200m ☐ 200-500m ☐ >500m

13. Daily water use per household:

☐ <20 ℓ ☐ 20 ℓ -50ℓ ☐ 50 ℓ-100ℓ ☐ 100 ℓ-150ℓ ☐ >150 ℓ

14. Time taken fetching water per day:

☐ < 15min ☐ 15-30 min ☐ 30-60min ☐ 1-2hrs ☐ > 2hrs

15. Volume of water that can be kept in the house:

☐ <20 ℓ ☐ 20 ℓ-50ℓ ☐ 50 ℓ-100ℓ ☐ >100 ℓ

16. What type of detergence do you use:

Bath soaps: ________________________ Washing powders: ________________

Dish washing liquids: _____________________ Shampoos: ________________

Other detergents (specify): ____

17. How often do you wash your clothes?

☐ Daily ☐ Once a week ☐ Twice a week ☐ More (specify): ___________

18. How often do you / members of the family take baths:

☐ ☐ ☐

Daily Twice daily Other (specify): ______________

19. What do you do with the dirty water after use?

☐ Throw away ☐ Water plants ☐ Re-use ☐ other (specify): ___________

20. If you re-use the water give examples (e.g. using cooking water for dishes or bathing water for laundry): ____

Section 3: Grey water Management

21. Do you think that grey water recycling would be useful in the community? Please give reasons for your answer: ________________________________

____

22. Which are the most important services that you think would make life better:

☐ Electricity ☐ Houses ☐ Water ☐ Toilets ☐ Schools ☐ Refuse removal ☐ Other (specify): _____________

23. Do you think grey water is a major health problem in the community? Give examples: ____

24. What would you suggest as the best way of resolving the problem of grey water disposal? ____

25. Do you have any questions you would like to ask me?

Appendix 3: Sampling sheet for laboratory work

Iso/IEC 17025:2005 Clause 4.3	**Request for Analysis**	**Doc ID:** **Subject: Request for analysis** **Date:** **Signature:**
Client Name:		
Contact Details:		
Address:		
Number of Samples	**Sources:**	**Time/ Weather:**

Physical Parameters	**Units**	**Operational alert**	**Unit**
PH		Aluminium	mg/l
Turbidity	NTU	Alkalinity	mg/l
Conductivity	mS/m	Calcium	mg/l
Total Suspended solids	mg/l	Chloride	mg/l
		Potassium	mg/l
Chemical Parameters		Sulphate	mg/l
COD	mg/l	Sodium	mg/l
Orthophosphate	mg/l		
Soap, Oil & Grease	mg/l	**Resources**	
Dissolved Iron	mg/l	Ammonia	mg/l
Dissolved Manganese	mg/l	Nitrogen	mg/l
		Nitrate	mg/l

Microbiological determinants		Nitrite	mg/l
E-Coli	CFU/100ml	Phosphorus	mg/l
Total Coliforms	CFU/100ml		
Heterotrophic plate count	CFU/100ml		

Appendix 4: Template for collection of samples

Name	House Number	Area	Time/weather	Number of Samples	Contact Details