UNIVERSITY OF ZIMBABWE

FACULTY OF ENGINEERING
DEPARTMENT OF CIVIL ENGINEERING

EVALUATION OF THE STATUS OF WATER QUALITY OF THE GREAT USUTHU RIVER, SWAZILAND

BY

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In collaboration with

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DECLARATION

I, **Thembeka Sanele Nkambule** state that this study is my own effort. The research project has never been submitted to any institution of higher education for any degree.

Signature:………………………….. Date:………………………….

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance.
APHA	American Public Health Association.
BOD	Biological Oxygen Demand.
CA	Cluster Analysis.
COD	Chemical Oxygen Demand.
DO	Dissolved Oxygen.
DWA	Swaziland Department of Water Affairs.
DWAF	South Africa Department of Water Affairs and Forestry.
DWQI	Dinius Water Quality Index.
FAO	Food and Agriculture Organization.
GDP	Growth Domestic Product.
GUR	Great Usuthu River.
IWRM	Integrated Water Resources Management.
NWA	National Water Authority (Swaziland).
PCA	Principal Component Analysis.
RWQ	River Water Quality.
SEA	Swaziland Environmental Authority.
SAWQ	South African Water Quality guidelines.
SPSS	Statistical Package for Social Sciences
SWSC	Swaziland Water Service Corporation.
SWQO	Swaziland Water Quality Objectives for surface water.

ABSTRACT

Surface water quality is deteriorating due to pollution caused by a number of factors that include anthropogenic activities, poor water quality management and climate change. The evaluation of River Water Quality (RWQ) status remains beneficial in controlling river water pollution and ensuring suitability of river water for intended uses. The Great Usuthu River is a primary water supply source for towns, rural areas, irrigation water and industrial water uses in Swaziland. Its water quality status has raised concerns from the general public and Environmental Management Agency in Swaziland. The study assessed river water quality status, its spatial and temporal variation and suitability for predominant uses. The study also sought to determine the magnitude of pollution. Bimonthly samples of RWQ were collected from 6 sites from 7 January 2016 to 29 March 2016. The collected water samples were analyzed at the Swaziland Water Services Corporation laboratory and the Water Services laboratory of the Department of Water Affairs in Mbabane. Parameters analyzed using standard methods included temperature, pH, Electrical Conductivity (EC), Dissolved Oxygen (DO) Biological Oxygen Demand (BOD), Total Coliforms (TC), *Escherichia coli* (E.coli), chloride, Total Alkalinity (TA), Total Hardness (TH), nitrates and colour. These parameters were required in deriving the Dinius Water Quality Index (DWQI) for assessing the overall RWQ status as is the practice in Swaziland. The study utilized the Principal Component Analysis (PCA) and Cluster Analysis (CA) to find critical parameters and optimal sampling points. Repeated measurements analysis of variance (ANOVA) was used to assess the significance of variations in water quality between the sampling sites and sessions. RWQ results were compared to local and international limits for domestic, irrigation and industrial water uses. The pollution load was estimated for the principal parameters. Average DWQI values ranged from 52.7 to 59.9, suggesting marginally suitable quality. PCA identified EC, E.coli, TC and colour as the key water quality parameters as they accounted for a total of 99.9% of the variance and individually 10.4%, 8.7%, 65.4% and 15.4% respectively. CA identified 4 key sampling points using the k means clustering algorithm. ANOVA showed statistically significant variation ($p<0.05$) between sites and sampling sessions in measurements for EC, temperature, pH, E.coli, DO, TH, TA, BOD, chloride, nitrates and colour and no significant variation for TC measurements ($p>0.05$). Suitability analysis indicated the RWQ was not suitable for the predominant uses in the study area. Pollution loads were in the range 0.2 tons/day – 256.4 tons/day for the biological oxygen demand, chloride, nitrates and total dissolved solids during the study period. Generally, it was concluded that the RWQ is not suitable for the current uses. EC, TC, E.coli and colour were the principal parameters and four monitoring points were identified as optimal. Addition of two more monitoring sites to the current 2 by the Department of Water Affairs (Swaziland) and treatment of river water prior to use is recommended. More awareness rising to rural people on the use and safety of river water is recommended to discourage raw use of river water. Monitoring of the principal water quality parameters more regularly is recommended. The study also recommends monitoring of pollution load more regularly.

Key words: Great Usuthu River, suitable, status, variation, water quality, water supply,

CHAPTER ONE: INTRODUCTION

1.0. Background

Water quality refers to the physical, chemical, biological and aesthetic (appearance and smell) water features for specific uses of water (Kgabi, 2015). Human health, aquatic ecosystems and different economic sectors such as agriculture, industry and recreation have been proven scientifically to be affected by water quality (Ross, 2008). Globally, surface water quality is deteriorating as a result of anthropogenic activities (Ariza *et al.*, 2007). In America, some rivers and lakes are considered unhealthy for swimming, fishing or even for aquatic life, as 40% of rivers and 46% of lakes are polluted (Martins, n.d.). Furthermore, water quality related problems can reach the extent of a disaster when not addressed in time (Ding *et al.*, 2015).

The global deterioration of river water has resulted in decreasing water availability for different specific uses (Zhang *et al.*, 2015). Biological, chemical and sediment deposits in the rivers have resulted in high pollutant levels (Wandiga, 2010). The United Nations estimates that globally, the wastewater produced is 1500 km^3 per annum (Ross, 2008). About 70% of the industrial wastewater and 80% of domestic wastewater from developing countries (especially Africa) are deposited untreated into the rivers, lakes and coastal areas, polluting existing water supplies (UN-Waters, 2009). Furthermore, it is likely that 28.4 billion US Dollars (5% GDP) annually is lost in Africa due to lack of good water quality (UN-WWAP, 2009)**.** In Africa, the deteriorating water quality has resulted in approximately 3.5 million deaths since the year 2005 (Aurecon, 2011). Water availability and water quality are critical concerns for many SADC member states (Ollis *et al.*, 2006). High water treatment costs, degradation of the ecosystem and increased production costs (agricultural, industrial and tourism) have been proven to be on the rise in Africa due to deteriorating water quality (UN-Water, 2014).

The Kingdom of Swaziland depends mainly on surface water for water uses and consumption is estimated to be 1500 million m^3 per annum (Tomasz *et al.*, 2007)**.** The potential supply of surface water in Swaziland is 2630 million m^3 per annum and the total guaranteed yield is about 1356 million m^3 per annum (Tomasz et al., 2007). The causes of surface water quality degradation in Swaziland include poor catchment management, agro-chemical run-off and discharge from industries and water treatment plants (Mthimkhulu *et al.*, 2005; Mhlanga *et al.*, 2006; Manyatsi and Brown, 2009). Among those affected is the Great Usuthu River. The Great Usuthu River Basin is part of the Maputo River Basin which is shared by the Republic of South Africa, Kingdom of Swaziland and Republic of Mozambique (Zheng *et al.*, 2008). The Great Usuthu River water quality situation was worsened by the drought which affected the Southern Africa region over the past decade. The significant recent reduction of the Great Usuthu River water levels has resulted in the increase of heavy metal concentrations and other pollutants in the water which may affect water use and aquatic ecosystems (Tomasz *et al.*, 2007). Climatic models assessing the impact of climate change in the Great Usutu River basin reveal higher temperatures and more intense rainfall in early summer (October to January), dissipating in late summer and winter (February to September). The projections also indicate a maximum reduction in annual runoff of up to 12.6% or 133.6 million m^3 (UN - Water, 2009).

A joint study was carried out for South Africa, Swaziland and Mozambique in the valuation of Maputo River Basin in 2007. The study assessed the RWQ of the Maputo River (also called the Great Usuthu River in Swaziland) as per the request of the Tripartite Permanent Technical Committee (TPTC) for the three countries as they are sharing the river (Zheng et al., 2008). In Swaziland, the Great Usuthu River basin was grouped into the Lusushwana sub catchment, Upper Usuthu sub catchment, Lower Usuthu sub catchment, Ngwemphisi sub catchment, Mkhondvo sub catchment and Ngwavuma sub catchment. The study indicated that salinity, EC, TDS, TA, TH, orthophosphates, organic pollution and sediment concentrations were high in all these Usuthu River Basin sub catchments due to agricultural runoff, industrial effluent discharge and poor sanitation (Zheng *et al.,* 2008). The industrial effluents released by the Matsapha industrial site (Lusushwana sub catchment) has led to the Swaziland Water Services Corporation’s overall compliance to effluent discharge water quality limits standing at 48% in the year 2014 due to the impact of the increased pressure on the plants from effluent released by industries, sewage from newly connected customers (SWSC, 2014)

Tomasz et al. (2007) also carried out a study on examining the metal contamination in the GUR. The study identified levels of heavy metals such as lead in the river. The study also found chemical oxygen demand values in the range 121 - 204 mg/l for Bhunya, 14 and 40 mg/l for Siphofaneni, Sandlane and Bigbend and 55 and 101 mg/l for Ngonini which exceeded the 10 mg/l limit as recommended by the Swaziland Water Quality Objectives (SWQO) for surface water. This could be the reason behind the loss of aquatic biodiversity observed in the basin. The study also showed concentrations of chromium, cobalt, lead and vanadium at high concentrations upstream the river and below drinking water quality guidelines downstream. The findings from the study showed Great Usuthu River was polluted (Tomasz et al., 2007). The increase in deteriorating river water quality makes monitoring very important in evaluating the suitability of the water for different uses (Mishra *et al.*, 2009).

1.1. Problem Statement

The river water quality status of the Great Usuthu River has raised concerns from the general public and the environmental management agency in Swaziland (SEA, 2008). A study was carried out upstream the Great Usuthu River to investigate water quality at the SAPPI Usutu Pulp Mill. The study indicated that the Sappi Usuthu Pulp Mill caused significant pollution to the river (Dlamini and Hoko, 2004). Other studies tended to focus on heavy metal concentrations in the Great Usuthu River (Tomasz *et al.*, 2007) and upstream tributaries such as Lusushwana and Mbabane Rivers (Dladla, 2009 and Mnisi, 2010). All the studies indicated that the river was polluted, yet fewer studies carried water quality assessment on the lower parts of the river where there is currently agricultural and industrial development. Furthermore, no recent study has been carried out to evaluate the current water quality status of the Great Usuthu River as it is of economic significance to Swaziland. This study therefore sought to measure the water quality situation of the Great Usuthu River and determine its fitness for domestic, irrigation and industrial water use in the study area.

1.2. Justification

The Great Usuthu River is the largest in Swaziland. It flows through Bhunya, Luyengo, Siphofaneni, and Big Bend towns and is the primary supply of water for irrigation, water supply for towns and industries (Dlamini *et al.*, 2014). The lack of alternative water supply in rural communities in the Usuthu River Basin such as Siphofeneni, Mkhweli, Mndobandoba has led to the use of untreated river water for domestic use and production uses (Governement of Swaziland, 2005). Livestock, pets and wild animals tend to use the river water, thereby contaminating it and increasing health risks to humans. There has also been significant agricultural and industrial development in the Usuthu River Basin which might be impacting the river water quality and influencing its suitability for inteded uses. There is, therefore, a need to evaluate the current river water quality status and determine its suitability for domestic, irrigation and industrial water supply uses as previous studies showed the river was polluted and there are current concerns regarding the river water quality. There is also a need to determine optimal sampling points and principal water quality parameters that would provide the utmost meaningful information on the river water quality due to the agricultural and industrial development that has taken place recently.

1.4. Research Objectives

1.4.1. General Objectives

The main objective was to assess the status of the water quality for the Lower Great Usuthu River and to determine its suitability for domestic use, irrigation and industrial uses for the period January 2016 to March 2016.

1.4.2. Specific Objectives

1. To assess the spatial and temporal variation in water quality and pollution loads for the period January 2016 to March 2016.
2. To determine key river water quality parameters and optimal sampling points in the study area.
3. To assess the river water quality status and suitability for predominant uses in the using in the catchment.

CHAPTER TWO: LITERATURE REVIEW

2.1. Water quality status

Clean, safe and adequate freshwater is vital for the survival of all living organisms and proper functioning of ecosystems, communities and economies (Mishra *et al.*, 2009). Declining water quality has become a global issue of concern as human populations grow, industrial and agricultural activities expand, and climate change threatens to cause major alterations to the hydrologic cycle (UN - Water, 2009). Industries globally are responsible for dumping an estimated 300 – 400 million tonnes of heavy metals, solvents, sludge and other wastes into surface waters each year (Kumar *et al*. 2013). About 70% of industrial wastes in developing countries especially in Africa are disposed of untreated into surface waters where they contaminate existing water supplies which pose health risks to nearby communities (UN - Water, 2009). Nitrate is the most common chemical contaminant in the world's groundwater aquifers and surface waters from agricultural runoff. The mean nitrate levels have risen by an estimated 36% in global surface waters since 1990 with the most dramatic increases seen in the Eastern Mediterranean and Africa, where nitrate contamination has more than doubled (UN - Waters, 2009).

Freshwater quality in parts of central Africa is declining, as a result of: pollution from industrial and sewage outflows; agricultural run-off; and saltwater intrusion (Mhlanga *et al.*, 2012). The Congo River has been recognized as one of the cleanest in the world, due to the absence of industry, large urban settlements and agriculture along its banks (Muthanna, 2013) . In Swaziland, water quality for rivers is deteriorating due to the expansion of industrial and agricultural activities (Dladla, 2009 and Mnisi, 2010). Water users in Swaziland have noticed that the quality of water passing through intensive agriculture areas is showing signs of nitrate or nitrite contamination which can place higher risks on human life (Manyatsi and Brown, 2009). Surface water quality status generally is deteriorating mainly due to human population growth, industrial and agricultural expansion and climate change.

2.2. Physico-chemical and microbial water quality parameters influencing river water quality status

River water flow, together with the concentration of water quality parameters, are essential in determining the water quality status of the river (Panchani *et al.*, 2013). However, there is variation in water quality parameter concentration and stream discharge among parameters with varying interactions in different rivers (Kumar *et al.*, 2013). The river water quality is influenced by a range of factors such as weather, runoff, and waste discharge which result in changes in water quality parameters. This can be observed in the variation of the impact that wastewater can have on receiving waters (Aurecon, 2011). The selection for the river water quality assessment method vary according to the needs and objectives (Coulliette and Noble, 2008). Primary water quality parameters such as pH and temperature are vital as they influence reactions in water and the concentrations of other water quality parameters (Kgabi, 2015).

2.2.1. Temperature

Temperature is one of the most critical water quality parameters as it influences concentration of other water quality constituents such as dissolved oxygen, heavy metal ions and pH (Coulliette and Noble, 2008). Water bodies undergo temperature changes due to variations in climatic conditions (Kgabi, 2015). The temperature of water may be influenced by atmospheric conditions and reactions taking place in the water. Aquatic organisms can survive in water temperature less than 28 ^{o}C (Ding *et al.* 2015). Higher water temperatures than 25^{o}C for prolonged period of time causes aquatic organisms to get stressed and die (Environmental Protection Agency, 2001).Temperature changes in water bodies can influence the distribution of marine species within an water body. Factors that can cause changes in water temperature for water bodies include weather changes, industrial effluent discharge on the water body and water infrastructure such as a hydro power station (Kumar *et al*. 2013). In conclusion, temperature affects other water quality parameters especially metal ions as it can result in changes in their concentrations or alter their forms.

2.2.2. pH

pH refers to the Potential of Hydrogen and serves as an indicator of the degree of acidity or alkalinity of the water (Environmental Protection Agency, 2001). Normal pH in fresh water is between 6 and 8 (Kirby-Smith and White, 2006). Many processes in water are influenced by the pH level which depends on the hydrogen ion concentration (Oyhakilome *et al.*, 2012). The pH levels in surface waters can render the water unusable for all or some water uses. For example, water with pH value less than 5 is not suitable for most aquatic organisms (Aurecon, 2011). pH can be used to sensitively indicate differences in water quality, thereby indicating the suitability of the water for intended uses (Yang *et al.*, 2008). As a summary, it can be deduced that pH values in water can also affect other water parameter in water. Low pH increases solubility of heavy metal compounds which in turn results in higher concentrations of heavy metals in water. Extremes in pH can also affect the palatability of the water.

2.2.3. Total Alkalinity

Total Alkalinity (TA) is the ability of water to neutralize acids added to the water and is expressed in mg/l(Environmental Protection Agency, 2001). TA is composed mainly of bicarbonate (HCO_3), carbonate (CO_3) and hydroxyl (OH-) ions and is expressed as mg/l of $CaCO_3$. There is a direct relationship between TA and pH, An increase in TA causes an increase in water pH (Kgabi, 2015). TA is also affected by flow regimes and the presence of carbonate rocks. River water alkalinity levels reaching 400 mg/l can be observed but such levels have less significant effect on water quality (Environmental Protection Agency, 2001). TA can also be affected by the denitrification process in water which increases alkalinity in river water. Normal alkalinity in river water is in the range 120 mg/l - 170 mg/l for unpolluted rivers (Ding *et al.* 2015). Total alkalinity, therefore, can be used as a measure of the river waters buffering capacity.

2.2.4. Phosphorous

Phosphorous is crucial to the stimulation of plant growth (Quevaulviller *at el.*, 2006). Phosphate and nitrates are the main nutrients required for phytoplankton growth, and consequently eutrophication, which depends on their abundance. The increase of phosphorous in water bodies can be attributed to artificial introduction due to human activity (Kgabi, 2015). The recommended limit for phosphorus in surface water is 0.7 mg/l (Environmental Protection Agency, 2001). Eutrophication can be a serious problem when nutrient levels are high with low renewal rate (Matta, 2014). It can be concluded that phosphorus in water is an essential element of life as it is required for growth in plants and a fundamental element for metabolism in animal bodies. However, high concentration of phosphorus in water bodies causes eutrophication.

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2.2.5. Dissolved Oxygen.

Dissolved Oxygen (DO) is vital because it supports the lives of aquatic organisms which also help break down organic compounds in water (Mishra *et al.*, 2009). DO can vary seasonally or in 24 hours depending on the temperature and the biological activity (Kgabi, 2015). DO concentration effects biodegradation speed in water bodies (Ding et al. 2015). DO is affected by entry of organic matter in to rivers especially from runoff during and after a rainfall event. DO in surface water should be greater than 5 mg/l in order to support a variety of aquatic life (Environmental Protection Agency, 2001). DO plays a very significant part in the breakdown of organic waste in the water. Lower concentration of dissolved oxygen means more accumulation of biological substances in the water.

2.2.6. Oxygen Demand.

Biological Oxygen Demand (BOD) is the quantity of oxygen needed to breakdown organic waste in water and measurement is obtained after 5 days (Finotti *et al.*, 2014). BOD reduces the amount of DO available for aquatic organisms (Kgabi, 2015). The levels of BOD in receiving waters is directly increased by the discharge of waste that is high in organic matter (Kgabi, 2015). These organic wastes emanate from municipal sewage, industrial wastewater and runoff from catchments. The recommended BOD level for surface water is less than 5 mg/l (Environmental Protection Agency, 2001).

Chemical Oxygen Demand (COD) is the amount of chemical compounds that will require oxygen to be broken down (Mishra *et al.*, 2009). COD is useful for the determination of wastewater quality requirement discharged into receiving waters in order to limit their impact

(Quevaulviller at el., 2006). The recommended COD level for surface waters is less than 20 mg/l (Environmental Protection Agency, 2001). Both COD and BOD require DO. The higher the oxygen required, the more organic matter and chemical compounds are in the water, hence more DO will be required to breakdown the compounds.

2.2.7. Chloride

Chloride is found in all water resources in the world with levels varying and reaching the highest in sea water (35000 mg/l) (Kgabi, 2015). The sources of chloride in fresh water can be soil, rocks and waste disposal directly or indirectly into receiving waters. Domestic wastewater is the richest source of chloride (Kumar *et al.*, 2013). The water containing chloride concentration above 250 mg/l has a salty taste and people can object to drink it or use it (Ding *et al.*, 2015). High chloride levels can make the water unsuitable for irrigation of certain crops or use of certain irrigation systems (Wang *et al.*, 2013). In rivers, the chloride concentration is in the range 15 -35 mg/l which is way lower than the drinking water quality standard value of 250 mg/l (Environmental Protection Agency, 2001). Chloride poses no health risks to humans, however high concentration can give the water a salty taste.

2.2.8. Electrical Conductivity (EC).

EC in water is a measure of the capability of water to pass electrical flow (Environmental Protection Agency, 2001). Electrical conductivity is correlated to Total Dissolved Solids (TDS) (Mishra *et al.*, 2009). Total Dissolved Solids (TDS) can be predicted using equation 1(Environmental Protection Agency, 2001).

$$TDS\left(\frac{\mathrm{mg}}{\mathrm{l}}\right) = \mathrm{EC}\left(\frac{\mu\mathrm{S}}{\mathrm{cm}}\right)\mathrm{x}\frac{2}{3} \qquad (1).$$

Increase in temperature results to increase in EC in water. The recommended EC level for surface water is less than 1000 µS/cm (Environmental Protection Agency, 2001). In conclusion, electrical conductivity is essential as it can be used as an indicator of total dissolved organics, bases, acids and salts in water. Measuring EC helps water resources managers assess water quality in terms of the presence of metal ions, salts and other pollutants that may render the water unsuitable for intended uses.

2.2.9. Nitrates

Nitrate is most commonly found from organic and inorganic sources such as fertilizers and waste discharges (Environmental Protection Agency, 2001). Nitrates can also be produced by bacteria and plants (Kgabi, 2015). Nitrate becomes more toxic to humans after converting to nitrite which can cause anemia as it combines with haemoglobin in red blood cells of humans (Elshorbagy and Ormsbee, 2006). Domestic wastewater contains high levels of nitrogen which can be converted to nitrate in water resources, thereby causing eutrophication (Mishra *et al.*, 2009). In streams or rivers, elevated nitrates concentrations are usually due to runoff from agricultural land and this causes significant increase in the nitrate content in receiving waters (Wang *et al.*, 2013). The recommended nitrate level for surface water is less than 50 mg/l (Environmental Protection Agency, 2001). The presence of nitrates in river water is a sign of agricultural runoff, storm drains and poorly functioning septic systems, thus suggesting the need for immediate action to be taken before the situation worsens.

2.2.10. Colour

For surface water, normal water colour is less than 150 mg/l Pt/Co (Environmental Protection Agency, 2001). People are not willing to drink coloured water even if safe because of the perceptions associated with coloured water (Wang *et al.*, 2013). People in certain parts of the world have even altered to other types of water supply due to the colour of water that they have been receiving from their existing supplies even though the water may have been safer (Elshorbagy and Ormsbee, 2006). Colour measurement for river water are at peak after heavy rainfall following a long dry season (Kgabi, 2015). Because of this variability, it is important that numerous measurements are complete to find the correct variety of colour in river water (Environmental Protection Agency, 2001). Therefore, colour is important when assessing suitability of river water especially for domestic uses or public water supply.

2.2.11. Total Hardness.

Total Hardness (TH) is the capacity of water to destroy the lather of detergents or soaps. Recent studies have shown that in developing countries the number of people dying due to heart diseases was lower in places where the water the people use was hard (Environmental

Protection Agency, 2001). TH consists of Calcium and Magnesium or Calcium Carbonate (Kgabi, 2015). The extensive richness these elements or compounds in rock foundations result in very high TH concentrations in river and groundwater (Remesan and Panda, 2008). TH at higher concentrations (>200 mg/l) can cause blockages in pipes, affect boilers in industries and neutralize the lathering properties of water (Wang *et al.*, 2013).

2.2.12. Total Coliforms.

Total Coliforms (TC) comprise of faecal and non faecal bacteria which may originate from soil or plant material. In water quality, TC is a sign for the presence of pathogens in the water (Environmental Protection Agency, 2001). Sources of bacteria can be the digestive system intestines for humans or warm blooded animals (Ding *et al.*, 2015). The possibility of getting infections from contaminated water depends on the number of pathogens in the contaminated water *(*Olorode *et al.*, 2015). In surface waters, TC concentration less than 1000 CFU/100 ml is recommended. But for drinking water and health reasons, it is recommended that only water without any coliform should be used to minimize the risk of contracting infections (Environmental Protection Agency, 2001). Total coliform in river water can be used as an indicator of the total bacteria or pathogenic organisms that can be found in the water. High total coliform count in river water is due to runoff from catchment, sewage discharge and poor sanitation.

2.2.13. Escherichia Coli

Escherichia Coli (E.coli) is an affiliate of the faecal coliform microbes and originates in the human intestines (Environmental Protection Agency, 2001). E.coli bacteria serves as an excellent sign for faecal pollution in water as they can live longer than other bacteria or disease causing organisms (Olorode *et al.*, 2015). However, their existence does not essentially justify that disease causing organisms are existing or present in the water, but rather shows a possible healthiness risk. Failing septic tanks, leaking sewer pipes, malfunctioning wastewater treatment plants, open defecation and stormwater runoff are possible E.coli sources in river water. For the safety of drinking water, the E.coli count should be 0 (Environmental Protection Agency, 2001). Analysis of water for E.coli is important for assessing microbial pollution in the water.

Occurrence of E.coli in water at high concentration means that the water is not safe for drinking and there is high possibility for waterborne infections such as diarrhea, cholera, and many more. This also helps in establishing weather the water is suitable for domestic purposes or not.

2.3. River water quality assessment.

Water quality assessment is mostly used to measure the magnitude of water resources pollution (Kgabi, 2015). Water quality assessment is the complete process of evaluation of the physical, chemical and biological nature of water based on human effects and intended uses (Mwangi, 2014). Globally, numerous deaths have been reported due to water resources not meeting the health criteria in terms of their constituents' concentration (Afiti *et al.*, 2015). Improved water resource management ensures that water resources have less risk of contamination and the water is suitable for both human lives and the environment at large (WHO/UNICEF/WSSCC, 2004).

Variation in water quality is caused by natural and anthropogenic activities (Li *et al.*, 2007). The spatial extent of pollution is critical as the mixing of pollutants occurs over a given distance (Islam *et al.*, 2007). It is vital to have accurate measurements for variability between sites and collection sessions in water quality of a river or any other watercourse (Elshorbagy *et al.*, 2006). The risk associated with pollution depends on both the extent of the temporal and spatial variation of the pollutant (Remesan and Panda, 2008).

2.3.1. Indices of water quality

Indices of Water Quality (IWQ) are simple expressions of a more or less complex combination of the quantity constituents which serve as a measure of water quality. In most cases it combines two or more parameters (UNEP, 2007). The output from an index is presented as a number, a class, a verbal description, a unique symbol or a colour code (Abbasi, 2012). There are various water quality indices for evaluating the water quality status for watercourses (Muthanna, 2013). Table 2.3.1 by Fernandez (2004) summarizes the differences between selected water quality indices used worldwide to evaluate status of water quality.

Water quality indices differ in various ways as shown in Table 2.2.1. Such differences are in the number of parameters they consider. Water Quality Indices consider varying number of parameters, ranging from a single parameter for example the Bacterial Pollution Index (BPI) to indices that use up 47 water quality parameters like the British Columbia formulas (Abbasi, 2012). Indices may use the same number of water quality parameters but different sets of parameters. Other noticeable differences in indices are in the aggregation formulae as some use sum (Miami River index), proportion weighted sum (Dalmatia WQI), quadratic equation (Washington WQI) and many more (Teegavarapu *et al.*, 2005).

Even in structure indices are different as some use diagrams, tables (Benthic Saprobity, Biological Diversity Index, Miami River Index and others), equations (Oregon WQI, Malaysia WQI), formulas (British Columbia) and many more. Table 2.3.1 shows a total of 14 indices and how they differ from each other mainly with emphasis on the three aspects; the number of parameters, structures and aggregation formulae. Since the study sought to assess the status of the Great Usuthu River water quality for intended use, attention was centered on the Dinius Water Quality Index (DWQI). This is so because the index was designed for evaluating water quality for 6 classes of water usages: community water supply, recreational water use, growing of fish and shellfish, farming and industrial water use (Tirkey *et al.*, 2013). Agricultural, domestic, recreation and industrial water uses are the most predominant water uses in Swaziland (Governement of Swaziland, 2005). Other water quality indices only give general water quality status and do not give water quality status for specific categories of water uses which help show if the water is suitable for those uses or not.

Table 2.3.1: Water Quality Indices

Index	Number of Parameters	Structure	Aggregation Formula
Water Quality Indices			
Bacterial Pollution Index (BPI)	1	Diagram	Direct reading
Bentic Saprobity Index	At least 30	Table	Percentage average
Biological Diversity Index	Indeterminate	Table	Proportion
British Colombia	Up to 47	Formulas	Harmonic square sums
Dalmaria	9	Formulas	Properties of weighted sums
Dinius (1987)	12	Equation	Weighted average
DEM	7	Diagrams	Weighted average
Greensboro	9	Diagrams	Un weighted multiplicative
Idalio	5	Equation	Logarithmic proportion
Leon (1998)	15	Formulas	Weighted geo average
Industrial Pollution Index	5 to 14	Diagrams	Weighted geo average
Malasia	6	Equations	Weighted average
Montoya (1997)	17	Equation	Weighted average
Miami River Index	7	Table	Sum
Nutrient Pollution Index	9	Weighted average modified	Weighted average modified

Adopted from: Fernandez *et al.*, 2004

2.3.1.1. DWQI – Dinius Water Quality Index

The DWQI was established by Dinius (Scientist) in 1987 and uses multiplication function in the form of an equation to come up with a single number which indicates the status of the water coarse being evaluated (Abbasi, 2012). The DWQI comprises of 12 water quality parameters which include: dissolved oxygen, biological oxygen demand, total coliforms, *Escherichia Coli*, pH, total alkalinity, total hardness, electrical conductivity, chloride, temperature, nitrates and colour. The weight per parameter is allocated depending on the assessment of significance as determined by the Delphi panel members (Tirkey *et al.*, 2013). Sub index functions for each parameter were developed using combinations of formulas and are presented in Table 2.3.1.1. Final DWQI value is a product of the weight and sub index function for all the parameters analyzed (Abbasi, 2012).

Table 2.3.1.1: Sub index function for Dinius Water Quality Index

Parameters	**Dimension**	**Weight**	**Function**
Dissolved Oxygen (DO)	% Saturation	0.109	0.82DO+10.56
Biological Oxygen Demand (BOD)	mg/l	0.097	$108(BOD)^{-0.3494}$
Total Coliforms (TC)	Coli/100ml	0.090	$136(Coli)^{-0.1286}$
Escherichia coli (E.coli)	Coli/100ml	0.090	$106(E.coli)^{-0.1286}$
Total Alkalinity (TA)	mg/l	0.063	$110(ALK)^{-0.1342}$
Total Hardness (TH)	mg/l	0.065	$552(HA)^{-0.4488}$
Chloride	mg/l	0.074	$391(CL)^{-0.3480}$
Electrical Conductivity (EC)	µS/cm	0.079	$506(SPC)^{-0.3315}$
pH	pH<6.9	0.077	$10^{0.6803+01856(pH)}$
	pH (6.9 – 7.1)	0.077	1
	pH>7.1	0.077	$10^{3.65-0.2216(pH)}$
Nitrates	mg/l	0.090	$125(N)^{-0.2718}$
Temperature	^{0} C	0.077	$10^{2.004-0.0382(Ta - Ts)}$
Colour	PtCo	0.063	$127(C)^{-0.2394}$

Adopted from: Abbasi (2012).

River water quality assessment is very vital for water resources management as it helps determine pollution loads in streams and rivers. The presence of pollutants in the water makes the water unsuitable for certain specific water uses. Evaluation of river water quality status therefore becomes very important. Water quality indices are simple expressions of a more or less complex numeric combination indicating water quality situation. The Dinius Water Quality Index serves as a good index for assessing water quality status for public water supply, recreation, agricultural water use and industrial water use.

2.3.2. Standards for water quality

Water Quality standards or guidelines originate from different countries such as European Union participant countries, individual countries, or international organizations such as the US Environmental Management Agency (Environmental Protection Agency, 2001). Developing countries face the challenge of lack of sufficient water quality data for decision making (WHO, 2011). Water quality data is required in the assessment of the suitability of water for intended uses such as drinking, industrial use, agricultural use and use in mines (Muthanna, 2013). The main aim of the imposition of water quality standards is the protection of the end uses of water, be it humans, the environment or industries (Environmental Protection Agency, 2001). The establishment of water quality regulations and monitoring programmes is critical for water resources planning and management (Tirkey *et al.*, 2013). Establishing appropriate standards requires information on the degree of tolerance of each of the specific use on the amount of contamination and possible effects (Environmental Protection Agency, 2001).

The Swaziland Environmental Authority Act of 1992 addresses the issue of pollution control for water and the environment and includes provisions for the establishment of standards. The Water Act of Swaziland of 2003 number 7 which came into force on March 2003 sets out water quality standards for environment and effluent discharge (Government of Swaziland, 2003). Appendix 1 and 2 show schedule one Swaziland Water Quality Objective for surface water (SWQO) quality standards and effluent discharge standards respectively. Water for drinking needs further treatment in order to reach the drinking water quality values as regulated by the law of Swaziland. The water is said to be polluted if the quality exceeds the limits as per the water quality guidelines. Investigation on the causes of pollution in the river is important as soon as the deviation is detected in order to prevent health and environmental impacts. According to CPH Water (2002), high levels more than stipulated by the water quality objectives of physico-chemical and microbial water quality parameters are indicators of water resources pollution due to poor sanitation, effluent discharge and agricultural runoff. Effluent discharging organizations, companies, and individuals are encouraged to treat the wastewater and ensure pollutants are removed before the effluent can be discharged into the river.

Water quality standards ensure that the water quality is maintained to a desirable level that will suit both human needs and the environment. However different countries and organizations have their own specific water quality standards and guidelines for that particular region depending on the geographic location, nature of contaminants in receiving waters, health hazards and intended uses. As water resources manager, taking into account the specific water quality requirements for different water uses per country or region is very essential.

2.3.3. Water quality models

Modelling can also be used in water quality assessment as it can simulate pollutants concentration in water and loads. This can be in form of mathematical equations, computer programs or even use of remote sensing which will in turn reduce costs drastically compared to physical means (Wang *et al.*, 2013). Water quality models also help simulate water quality conditions because field experiments cost too much, take too much time and pollute the environment (Singh, 2014). The development of models for water quality depends on the various objectives and purposes, and based on a number of different modeling techniques (Elshorbagy and Ormsbee, 2006). In conclusion, water quality models can also evaluate water quality or make further assessment of the water quality from primary or secondary water quality data. This can be used in the estimation of pollution load, assessing current and future trends in water quality or assessing suitability for intended uses. Therefore, for this study, the modelling approach in form of pollution load estimation was used.

2.3.4. Multivariate analysis of river water quality data.

The multivariate analyses of the river water quality data are performed through cluster analysis (CA), principal component analysis (PCA)/factor analysis (FA), discriminant analysis (DA) and descriptive statistics. The application of different multivariate statistical techniques helps in the interpretation of complex data matrices to better understand the water quality and ecological status of the studied system. Such tools facilitate the identification of possible factors that influence water quality and can aid in the reliable management of water resources as well as rapid solution to pollution problems (Lei, 2013). Multivariate statistical techniques have been applied to characterize and evaluate freshwater quality, and are useful in verifying temporal and spatial variations caused by natural and anthropogenic factors linked to seasonality (Singh *et al.*, 2005)**.**

It is also useful in verifying spatial and temporal variations caused by natural and anthropogenic factors. Lomniczi et al. (2007) has also characterized the pollution sites by using principal PCA while working on Arenales River (Salta) Argentina. In China, Xin’anjiang River, a study was conducted to assess temporal and spatial variations in water quality using multivariate statistical methods such as CA, DA and PCA (Li *et al.,* 2014). Multivariate statistical analysis therefore has demonstrated to be a useful statistical tool that can be used to identify optimal sampling points, critical or key water quality parameters and analysis of the spatial and temporal variations in water quality.

2.4. Pollution loads in rivers and their impacts

About 75% of earth surface is enclosed with water and is necessary for life (Quevaulviller at el., 2006). Fresh water accounts for only 6% of the world’s water supply, however due to water resources pollution fresh water quantity is decreasing (Peter and Gleick, 2006). Water of good quality supports aquatic ecosystems and the environment, therefore contaminated water is detrimental to the health of living organisms and the environment (Singh, 2014). Contaminated water incurs higher water treatment costs for different specific uses such as drinking and recreation due to the need to remove the contaminants (Matta, 2014). With the increase in temperature due to climate variability, the high evaporation rates reduces the surface water resources ability to dilute pollutants in the water (Peter and Gleick, 2006). Coupled with discharges from industrial areas and wastewater treatment plants, this causes increase in the mass loads of pollutants on rivers (Roy *et al.,* 2014).

Water resources remain unprotected towards great quantities of domestic, industrialized, farming, mining and several other types of wastes (Wongsupapa *et al.*, 2009). The contamination or pollution of water resources is characterized as diffuse pollution or non-diffuse pollution (Panchani *et al.*, 2013). A good example of diffuse pollution is runoff especially after rainfall (Kirby-Smith and White, 2006). It has been demonstrated by several studies that runoff after rainfall is the major source of pollutants in many rivers throughout the world (Coulliette and Noble, 2008). The catchment activities coupled with runoff from the catchment, open defecation and upstream pollution might be the leading factors causing the lower water quality status (Buijs, 2007).

According to Finotti *et al.* (2014) agricultural plantations and cities are large emitters of nutrients and contaminants that reduce biodiversity and human health. Untreated sewage discharge, combined with sewer overflows, solid waste disposal and stormwater runoff are the largest causes of urban water pollution (Shuster *et al.*, 2005). By the year 2010, only 14 of the 310 residential centers had their domestic wastewaters treated at the wastewater treatment plants in the Kızılırmak Basin. These treatment plants in the watershed served 1,387,038 people, which refer to 37% of the watershed population. Fractions of the pollutant loads from urban wastewater sources, which were discharged to the watershed, were 51% for COD (56,317 tons/year), 67% (5,777 tons/year) for total nitrogen (TN), and 69% (973 tons/year) for total phosphorus (TP) (Fatoki *et al.*, 2003).

Water resource management and improved sanitation combined with waste water treatment can greatly reduce pollution of water resources (Ligtvoet *et al.*, 2014). The point-source pollutant loads from the sanitary landfill leachates in the Kızılırmak Basin for the year 2010 stood at the levels of 70 tons/year for COD, 17 tons/year for TN, and 0.18 ton/year for TP. These loads are expected to drastically increase when the sanitary solid waste landfills will be launched into operation by the year 2016 according to the Solid Waste Master Plan (Fatoki *et al.*, 2003). Similarly, for surface water recommended loads for chloride, total dissolved solids and sulphate are less than 1.43 tons/day, 438 tons/day and 268 tons/day (Morita *et al.* 2013). According to the Texas Natural Resource Conservation Commission (TNRCC), for surface water to be suitable for the environment and human health, chloride daily loads should be less than 1.43 tons/day, nitrates should be less than 146 tons/day and total dissolved solids load should be less than 438 tons/day (TNRCC,. 2003).

As a summary, the contamination of water resources is mostly initiated by human activities such as agriculture, household and industrial wastewater discharge which makes the water unsuitable for different specific uses and for aquatic ecosystems. Runoff is the major contributor to pollution loads in rivers. Pollutions loads in rivers affect the use of water and sustainability of the resource. Preventing or controlling water resources pollution, therefore, is key in ensuring water resources such as rivers are suitable for different uses and available for future generations.

CHAPTER THREE: STUDY AREA

3.1. Location

The Great Usuthu River (GUR) flows through the Republic of South Africa, Kingdom of Swaziland and Republic of Mozambique (Dlamini *et al.*, 2014). The Great Usuthu River originates from the north east of South Africa and passes through central Swaziland before entering Mozambique on the lower side (Tomasz *et al.*, 2007)**.** The study area (Lower Great Usuthu River) is situated between latitudes 26^{o}40’60”S, 26^{o}46’77”S and longitudes 31^{o}40’60”E, 31^{o}55’48.88”E. The location of the study area is shown in Figure 3.1. The elevation varies from 160 m to 168 m (Government of Swaziland, 2009). It is estimated that the GUR has basin area of 2682 km^2 in Swaziland (Dlamini *et al.*, 2014)**.**

The Great Usuthu River meanders through the towns: Siphofaneni, Big bend and Matata before joining Mozambique. The Lubovane Dam was constructed on the Mhlathuzane River. A feeder canal was constructed to convey water from the Great Usuthu River to the Lubovane dam as additional water. The canal only harvest flood water from the Great Usuthu River. After Lubovane Dam, the Mhlathuzane River meanders over the catchment before connecting to the Great Usuthu River.

3.2. Population

The Usuthu River Basin covers two thirds of the size of Swaziland and 75% of the entire Swaziland people lives in the catchment. The Usutu River Basin has an area of about 12 000 km^2 (Matondo, 1997)**.** The population growth rate percentage according to the 2012 estimates was 1.195 % and the population for the kingdom was 1 419 623 in 2014 (Wikipedia, 2016). Using the growth rate of 1.195 %, the current population for the country is estimated to be 1,453,756, therefore for the entire Usuthu River Basin, the population is estimated at 1, 090, 317.

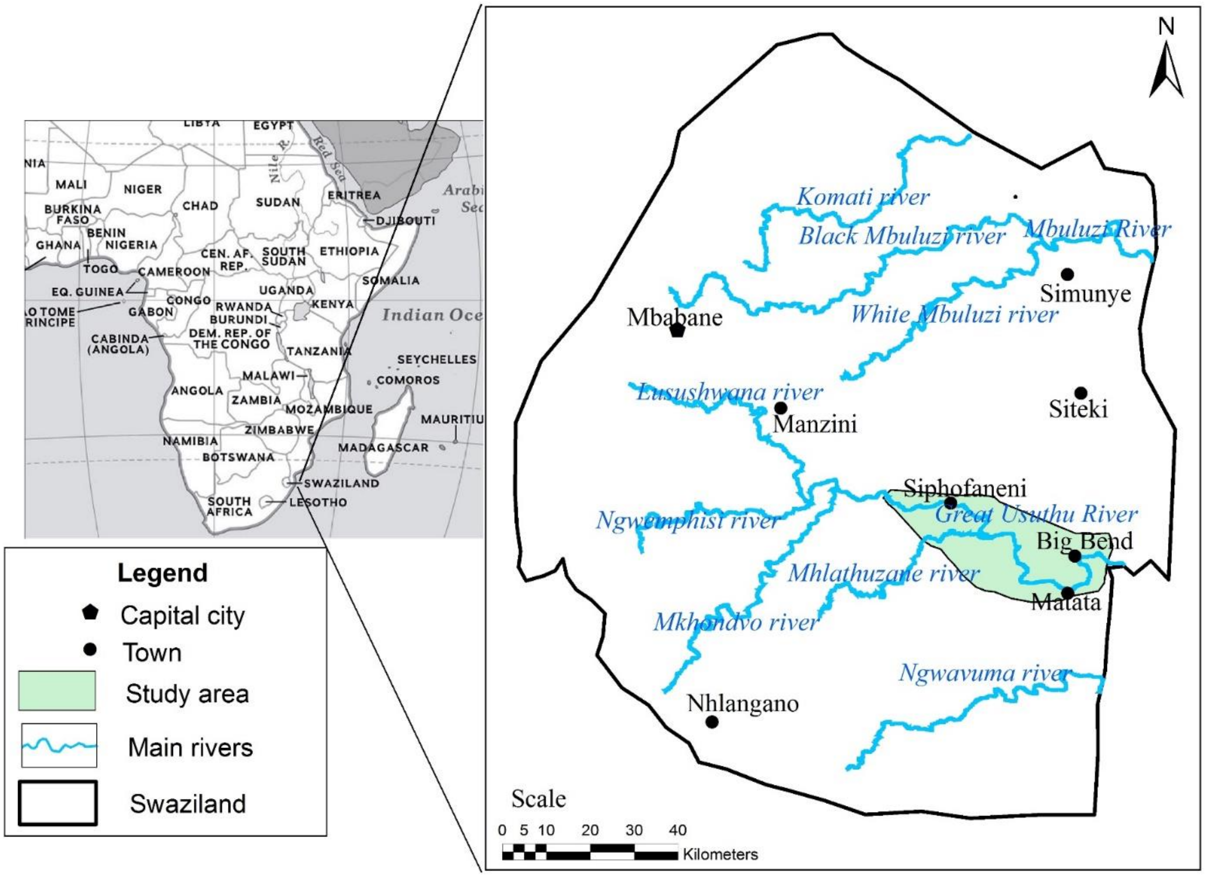


Figure 3.1: Study area Map

3.3. Socio Economic Activities

The Usuthu River Basin is of economic significance in Swaziland. it supports sugar cane production, hydro power generation and sugar and ethanol industry (Mhlanga *et al.*, 2012). The Usuthu River Basin also support citrus, maize and cotton production with maize being the stable food crop (Government of Swaziland, 2005). The basin also supports livestock production. The Lower Usuthu Small Holder Irrigation Project (LUSIP) is also located within the Usuthu River Basin and its purpose was to address the lack of irrigation water for poor farmers. The Swaziland Water Services Corporation (SWSC) abstracts water from the Great Usuthu River, treats it then distributes it as potable water to towns and peri urban areas like Bhunya, Sidvokodvo and Matsapha for various uses. People in places such as Mahlabaneni, Siphofaneni, Mndobandoba, Mhlabubovu and Mhlangeni lack treated water supply and thus tend to use the river water directly for domestic and production uses (Tomasz *et al.*, 2007)**.**

3.4. Climate

The study area is hot in summer and cold in winter with average temperatures ranging between 19 ^{o}C and 30 ^{o}C annually (Government of Swaziland, 2009). The basin averages yearly rainfall of approximately 900 mm and average latent evapotranspiration is approximately 1270 mm. The stream flow over rainfall ratio for the study area is estimated to be 0.16 (Tomasz *et al.*, 2007)**.** It is estimated that 70% yearly rainfall in the study area is received between October and March during summer (Government of Swaziland, 2009).

3.5. Hydrology and topography

The GUR is perennial, though occasionally reduced river flows are observed during the dry period (Tomasz *et al.*, 2007)**.** The 218 m long weir across the Usuthu River was constructed to harvest flood water during the wet season to fill an off-river 155 million m^3 Lubovane Reservoir along the Mhlatuzane River (Dlamini *et al.*, 2014). The Usuthu River Basin cuts through three agro- ecological zones, with tributaries from the Highveld, Middleveld and Lowveld. The general topography is comprised of undulating landforms (Dlamini *et al.,* 2014). Thus it is good farming land. The lowest point above sea level is 201 m (Government of Swaziland, 2009).The basin inflow is about 6.96×10^8 m^3/ annum and the outflow is about 23.57×10^8 m^3/annum *(*Mhlanga *et al.*, 2012).

3.6. Water quality management in Swaziland.

The management of water resources in Swaziland has been based on specific purposes using various legislative instruments spread across various government ministries and organizations with no coordination. Water sector reforms resulted in the 2003 Swaziland Water Act, which replaced the 1967 Swaziland Water Act. This resulted in the country living a coordinated way and having a clear national water policy on managing water resources and use (Dladla, 2009). The act encompasses the IWRM principles (SWP, 2008). The IWRM principles ensures that water resources are managed at catchment level and decision making is done at the lowest appropriate level with full participation of the stakeholders (GWP, 2000).

The main institutions responsible for land and water resources management are the (NWA) National Water Authority and Swaziland Environmental Authority (SEA). NWA is a premier institution created in 1967, responsible for development, distribution, control, and conservation of water resources (Swaziland Water Act of 2003). Nonetheless, SEA is responsible for pollution control and ensures that compliance certificates are issued after proponents of projects have done EIA (Environmental Impact Assessment) and Comprehensive Mitigation Plan (CMP). This is a requirement from the SEA Act of 1992 so as to protect water and other natural resources from pollution. With regard to irrigation projects, the Swaziland Government Water Act of 2003 requires a feasibility study where the proponents of the project are expected to state how they will protect and control land degradation due to water use and reclaim soils where irrigation would cause avoidable degradation. Overall, the Government of Swaziland regulates, and co-ordinates all water use agencies in the country, regulating and monitoring the quality and quantity of water resources.

The various types of pollution such as domestic and industrial wastewaters may potentially affect the river water quality as the common ways of releasing these types of pollutants via river. In the study area, the river is receiving wastewaters from various point and non-point sources via. industrial, municipal, domestic and agricultural runoffs (Tomasz *et al.*, 2007). The Government of Swaziland (DWA) operates a routine water quality monitoring network with monitoring points distributed widely over all river basins in Swaziland (Zheng *et al.*, 2008) . The Usuthu River Basin has a total of thirty eight water quality monitoring stations which are monitored. Among the thirty eight stations, four are located in the Lower Usuthu River Basin and two are within the study area for this study. These are located at Siphofaneni (Gauging station 6) and Bigbend (Gauging station 16). The Water Resources Laboratory collect water samples from the sampling sites and analyze them for thirteen water quality constituents and a further eight water quality constituents as per the need of the water quality monitoring (Zheng *et al.*, 2008). However due to financial constraints, the water quality monitoring is not carried out routinely and this makes water quality monitoring not efficient.

The slow implementation of the Water Act of 2003 and water management strategies has resulted in the management of water resources not being effective in Swaziland particular due to governance and decentralizing of responsibility taking too long (Manyatsi and Brown, 2009). The Water Act of 2003 also has regulations on penalties and fines for non-compliance to the above effluent discharge standards (SADC, 2012). Since implementation of the act requires that water resources management be done at catchment level, the slow decentralization process in has made water quality management status lower in Swaziland (Manyatsi and Brown, 2009).

CHAPTER FOUR: MATERIALS AND METHODS

4.1. Research Design

The study employed quantitative data collection methods between the period 7 January and 29 March 2016. A water quality sampling programme was established for the Lower Great Usuthu River featuring 6 sampling points.

4.1.1. Selection of study sites

The project was carried out in the lower parts of the Great Usuthu River following the general public and Swaziland environmental management agency concern (SEA, 2008). The Lower Great Usuthu River is characterized by irrigation, settlements, and sugar and ethanol industry (Dlamini *et al.*, 2014). The area was selected because of its high surface water usage from various competing cross-sectoral uses such as, households, industries and agriculture. The area was also selected due to its economic importance to the country (Government of Swaziland, 2009).

4.1.2. Selection of sampling sites

There were six purposively selected sampling points which were chosen and utilized. The selection of the sampling points followed recommendations as per the Red River Water Quality Monitoring Manual by Mark and William (2005) and the USGS Field Manual for the Collection of Water (2006). According to the Red River Water Quality Monitoring Manual, selection of sites for water quality monitoring should take account of aquatic life habitats, public health, economic water uses, and tributary impacts. Also considered were issues including whether the site had water at the time of sampling, safety, access to the site and lastly identification of the site on a map. According to the USGS Field Manual for the Collection of Water (2006), sampling sites for flowing rivers should be situated at river gauging stations so that flow data may also be recorded. The manual also recommends that the sampling sites should be located in straight reaches in order to get well mixed water. Table 4.1.2 shows the description and justification of the sampling points that were used during the study. Figure 4.1.2 shows the location of the sampling points.

Table 4.1.2: Description of sampling points.

Sampling Site	Location /Coordinates		Justification	Description
	X	Y		
Site 1 Mphaphati	31.557328	-26.674303	Point used as a reference point aimed to capture less impacted conditions of the River. Less settlements, no irrigated fields and also no industries around	Located at Mphaphati water intake for the feeder canal supplying water to Lubovane Reservour.
Site 2 Siphofaneni	31.680783	-26.688117	Point meant for capturing the status of the river after the discharge from WWTP and set of irrigation fields	Point located at the River Gauging Station 6 at Siphofaneni Town
Site 3 Madlenya	31.742436	-26.735100	Point meant for capturing the status of the River after the Lubovane dam and irrigation fields. Before joining Great Usuthu River.	Point is located at the confluence of the Mhlathuzane River and the Great Usuthu River
Site 4 Mndobandoba	31.908028	-26.857017	Point for capturing the conditions of the river after the irrigation fields, settlements and before receiving effluent from USA Distillers Factory	Point located at the bridge connecting mainroad to Bigbend from Mndobandoba
Site 5 Riverside	31.968356	-26.847831	Point for capturing the conditions of the river after the irrigation fields and effluent discharge from USA Distillers Factory.	Point located adjacent to the USA Distillers factory.
Site 6 Big Bend	31.999831	-26.802825	Point for capturing the state of the river after effluent discharge from ILLOVO Sugar factory and before river joins Mozambique	Point located at River Gauging Station 16 in Bigbend. Situated after the Ubombo Sugar Factory

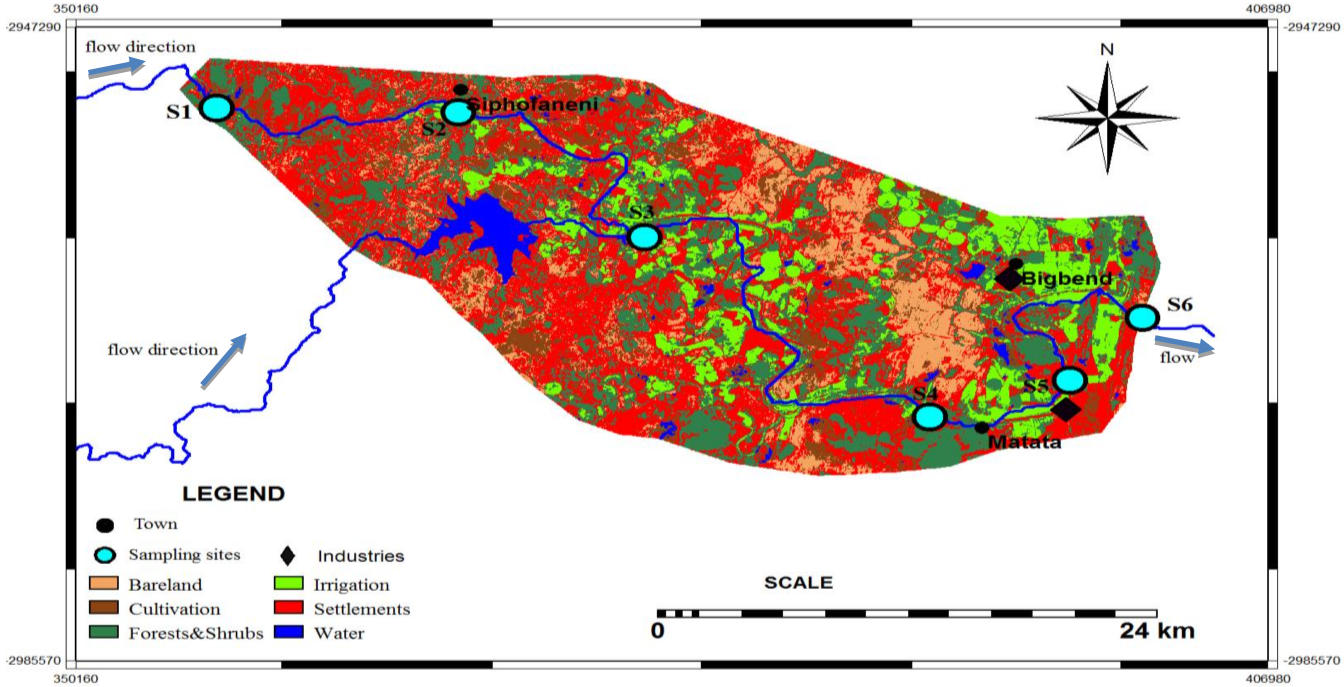


Figure 4.1.2: Map showing location of the sampling sites

4.1.3. Selection of water quality parameters

Since the Dinius Water Quality Index (DWQI) was used to measure the status, the parameters required for DWQI computation were the key parameters measured during the study. The parameters included dissolved oxygen, biological oxygen demand, total coliforms , Escherichia coli, pH, total alkalinity, total hardness, electrical conductivity, chloride, temperature, nitrates and colour (Abbasi, 2012). The DWQI is a water quality index for specific uses including public water supply, agriculture and industrial water use among others (Abbasi, 2012). These water uses are the same water uses that are dominant in the study area (Government of Swaziland, 2005), thus the DWQI was most appropriate for assessing the Great Usuthu River water quality as the study also sought to look at suitability of the river water for domestic water supply uses, irrigation water supply uses and industrial water supply uses in the study area.

4.1.4. Methods of sampling and frequency

The grab sampling method was used in the collection of water samples. According to Danielson (2013), grab sampling is recommended for regular-flow streams or rivers. The USGS Field

Manual recommends depth integrated samples for flowing surface water collected and mixed to form composite samples (USGS, 2006). Depth integrated sampling was done at each sampling point and a sampler was used (see Appendix 3). Bimonthly samples were collected at the six sampling points starting from 7 January 2016 to 29 March 2016. River flow data was also collected at the same time of sampling at Site 2, 3 and 6.

4.2. Data collection methods

4.2.1. Sampling

According to standards methods for water and wastewater by APHA (2005), 500 ml polypropylene bottles for physicochemical parameter and 500 ml pre-treated glass bottles are recommended for biological sampling, therefore these were used in the study. The collected samples were kept in a cool box with ice cubes/ice packs during transportation and were cooled at 5 ^oC. The water was collected at different depths using a sampler specifically designed for depth integrated samples. The collected water was then mixed to form composite samples.

4.2.2. Water quality testing

Water quality was tested on site (Great Usuthu River) and at two laboratories, namely the Swaziland Water Services Corporation Laboratory (SWSC) and the Water Resources Laboratory (Government of Swaziland) in Mbabane. This was done to ensure all the parameters required by the study were measured as the water resources laboratory could not analyze all parameters. The water quality parameters were examined by means of the standard methods prescribed by APHA (2005). Parameters such as 5 day biological oxygen demand, coliforms, E.*coli*, alkalinity, dissolved oxygen, hardness, chloride, colour and nitrates were analyzed in the Laboratory. The parameters analyzed onsite were temperature, pH and electrical conductivity.

4.2.2.1. Onsite Measurements

Onsite quantification of temperature, pH and EC was completed using a Hach Pc Multi Direct Meter with a Galvanic probe (see Appendix 3). Galvanic probe does not need time to stabilize. The onsite measurements were taken immediately after the sample was collected (see Appendix 4) as recommended by APHA (2005). The meter was recalibrated before measurements were taken so as to ensure accurate readings.

4.2.2.1. Laboratory analysis

Physico-chemical analysis was done at the Water Resources Laboratory (DWA) using the Lovibond Multi Direct Photometer for examination of alkalinity, total hardness, total orthophosphates and chlorides (see Appendix 3). The PC Multi Direct is easier to use, has a large screen and a microprocessor for the ease of analysis of water quality parameters (Dladla, 2009). The specific reagents used are summarized in Table 4.2.2.1.

Table 4.2.2.1. Reagents used at Water Resources Laboratory (DWA).

Water quality parameter	Reagent
Total Alkalinity (TA)	ALK –M- Photometer Tablet
Chloride	Chloride T1
	Chloride T2
Total Hardness (TH)	Hard check P –AD1660
Phosphates	Phosphates No. 1 LR
	Phosphates No. 2 LR

For nitrates and colour, the Hach DR 2000 Spectrophotometer was used. Again the user manual for the spectrophotometer was used and specific codes and instructions were followed. For nitrates, the reagent used was NitrVer 5 reagent powder. Total coliforms and feacal coliforms were analyzed using membrane filtration method which made use of 100 ml of sample water, filter media, membrane filters, vacuum pump and oven for incubation within 48 hours at 37^{o}C. Due to the nature of the river water and high coliform count, the sample water was diluted (10 ml sample and 90 ml distilled water).

At the Swaziland Water Services Corporation Laboratory (SWSC), DO, BOD, COD and E.coli were analyzed using standard methods. Dissolved oxygen is recommended to be measured in situ. However, after failing to get a multi meter with a dissolved oxygen probe, the dissolved oxygen was analyzed at the laboratory. Immediately after sample collection, the polythene bottle containing sample was closed and kept inside a cooler box with ice cubes. Laboratory analysis begun 3 to 4 hours after sample collection on the same day. According to APHA (2005), for preservation of dissolved oxygen, if analysis is not possible to be done immediately after sample collection, the sample should be kept below 10 ^{0}C to arrest any biological activity in the water that may deplete the dissolved oxygen and analysis should be carried out within 6 hrs.

Table 4.2.2.2. Laboratory equipment used and parameters measured at Water Resources Laboratory (DWA)

Equipment	Parameters
Hach Spectrophotometer DR 2000 Meter	Colour
Hach Spectrophotometer DR 6000 UV Meter	Nitrates
PC Multi Direct Meter	Alkalinity
	Hardness
	Phosphates
	Chlorides
Vacuum Pump, Membrane Filters, Glass Vessel	Total Coliforms

4.2.3. Quality Assurance

Before sampling, all sampling bottles were sterilized a day before sampling in order to reduce contamination of the samples. The multimeter was tested, recalibrated and prepared prior to sampling. To prevent cross contamination with previous samples, none sterile bottles for physico-chemical samples were rinsed once with the sample waters. Onsite water quality measurements were done immediately after collecting water sample as also recommended by Alpha (2005). Samples were put away in a cooler containing ice cubes and packs to minimize the influence of temperature on the water quality parameters during transportation. Laboratory analysis begun on the same day of sampling for accurate measurements of the water quality parameters. Split samples were also done to check for consistence of the laboratory results. Split samples were given the different site codes and sent to SWSC laboratory. The results showed consistence.

4.2.4. Field Surveys

Field surveys were carried out within the study area to identify sampling sites and attributes. GPS coordinates were collected at sampling sites which were located upstream and downstream potential sources of river water pollution using a Garmin GPS 60 CSx (See appendix 4). Field observations and google earth imagery were used to guide the survey and identification of sampling sites taking into account also the safety and access to the areas within the study area.

4.2.5. River flow measurements

Pollution load is a product of concentration of pollutants and river flow rate as required by the pollutant load estimation models (Richards, 2008). At the time of sampling for water quality measurements, river flow data was also collected. Only sampling sites with river gauging stations had river flow measurements taken. This was due to the non-availability of the current meter for measuring river flow rate. River flow data was successfully collected at Site 2 (Gauging station 6), Site 3(Gauging station 19) and Site 6 (Gauging station 16) (see Appendix 4).

4.3. Methods of data analysis and interpretation

4.3.1. Spatial and temporal variation assessment of RWQ along the Great Usuthu River.

The spatial extent of pollution is critical as the mixing of pollutants occurs over a given distance. Temporal variation is the assessment of the effect of time on pollution such as the seasonal pattern and its effect on the constituent's relationship (Kannel *et al.,* 2007). Spatio-temporal variation of river water quality was analyzed using SPSS software version 23. Firstly, the Shapiro-Wilk and Kolmogorov Smirnov (KS) tests were run to examine the normal spreading of all variables (Yang *et al.*, 2009). The KS test revealed that the data was not generally spread as $p>0.05$ for all parameters. Non parametric statistical tests were then used (Elbag, 2006). In SPSS, the ANOVA for repeated measurements was done to examine the substantiality of differences of the water quality parameters at the different sampling points over the six sampling sessions as recommended by Pallant (2013).

The contaminant load is the unit mass of a pollutant passing through a section of a river at a given time frame (EPA, 2009). The estimates of pollution load were processed and analyzed using Source Monitoring Method which basically uses numeric equation developed by EPA (2009). This method is based on monitoring river flow over the sampling period and the pollutant concentration. Pollution load is then estimated using the following equation:

$$\textbf{Pollutant load} = c \times q \qquad (2).$$

Where: c is the pollutant concentration measured at the sampling site and q is the river flow rate or discharge at the sampling site or gauging station. Equation 3 was incorporated on Microsoft Excel version 2013 and the water quality variables were inputted in order to come up with the load estimates. Since electrical conductivity is correlated to Total Dissolved Solids (TDS), TDS was used in the estimation of pollution load instead of electrical conductivity. The TDS concentration was estimated using equation 3.

$$TDS\left(\frac{mg}{l}\right) = Electrical\ Conductivity\left(\mu\frac{S}{cm}\right) \times 0.8 \qquad (3).$$

The computed TDS was then used as input to pollution load estimation equation (3) to come up with the pollutant load. Average conversion factors for deriving TDS from EC range between 0.5 and 0.9 (APHA, 2005). Pollution load estimation was only carried out for biological oxygen demand, chloride, nitrate and total dissolved solids as these are the only parameters among the 12 assessed during the study period that are eligible for computation of loads. Pollution load computation is recommended for key water quality parameters and those that are eligible for load computation. This is helpful in the quantification of the magnitude of pollution for water resources (Ayaz *et al.*, 2013).

4.3.2. Determination of key water quality parameters and optimal sampling points

The key water quality parameters that had significant loading to the overall variability of the data set were identified using the Principal Component Analysis (PCA) as recommended for water quality assessment (Gajbhiye *et al.*, 2015). The selection of the principal components which were used in the selection of the key water quality parameters was done using a scree plot and eigenvalues for the different components. The loadings of each parameter were classified in terms of their contribution (%) to the overall water quality variance. Cluster analysis was conducted to explore whether previously undefined clusters (groups) may exist in the dataset using the similarity of the water quality constituents values (Fataei, 2011). The k means clustering algorithm was used because it groups variables into clusters by estimating the mean of a set of k groups (k being a positive integer). The number of clusters established is the number of minimum water quality sampling points that should be in the study area.

4.3.3. Estimation of river water quality status using DWQI.

The Great Usuthu River (GUR) water quality status was analyzed using Dinius Water Quality Index (DWQI) (Abbasi, 2012). The values for each of the 12 water quality parameters measured (DO, BOD, pH, Temperature, TC, E.coli, Chloride, Nitrate, Colour, EC, TA and TH) over the sampling campaigns were inputted at each specific parameter sub index function as shown in Table 2.3.1.1. The weightage of each parameter was included in the sub-index function to come up with a sub-index value. The specific sub-index equations were joined using multiplicative combination function as follows:

$$\mathrm{DWQI} = \prod_{i=1}^{n} \mathrm{Ii}^{\mathrm{Wi}} \qquad \mathbf{(4)}.$$

Where by: DWQI = Dinius Water Quality Index values in the range 0 – 100.

Ii = Sub index function of DWQI pollutant parameter (see Table 2).

Wt = Unit weight of the DWQI pollutant parameter in the range 0- 1 (see Table 2).

N = Number of parameters

This was done for each sampling site and each sampling campaign between 7 January 2016 and

29 March 2016. The overall DWQI value was the average of the DWQI values for each site over the six sampling campaigns and was calculated using Microsoft Excel function. The classification of the river water quality status was then analyzed using the following categories/classes as shown in Table 4.3.3.

Table 4.3.3: Dinius Water Quality Index classification of water resources

DWQI values	Classification/ Status for Water Quality
90>	I. Excellent
65-89	II. Permissible
35-64	III. Marginally suitable
11-34	IV. Inadequate for use
10<	V. Totally unsuitable

Adopted from: Abbasi, 2012.

Since the DWQI assesses water quality status for domestic (public water supply), recreational, agricultural and industrial water uses, the study further compared the water quality results with water quality guidelines for surface water, drinking water, irrigation and industrial water quality guidelines. The physico-chemical and microbial water quality parameters measured during the study period were firstly analyzed to come up with average values (mean) using Microsoft Excel. These average values were then compared to the Swaziland Water Quality Objectives for surface water (SWQO) to check if the measured water quality parameters met the national maximum allowable values for surface water. The measured water quality constituents were also compared against the Swaziland Water Services Corporation (SWSC) drinking water quality guidelines, irrigation and category 3 industrial water use guidelines for South Africa (SAWQ) to check if the river water quality met the local (national) limits for irrigation and industrial water uses.

The Great Usuthu River is the main source of water supply for domestic purposes, irrigation purposes and industrial purposes within the Usuthu River Basin (Government of Swaziland, 2005). Also worth noting is that at some parts of the catchment for example, Siphofaneni, Mkhweli and Mndobandoba, rural villages use river water for domestic and production usages without any treatment (Tomasz *et al.*, 2007). The population depending on the river water for domestic uses in the above named areas is estimated at 37 907 (Dlamini *et al.*, 2014).

The water quality parameters tested were also compared against the World Health Organization (WHO) drinking water quality standards and irrigation water quality guidelines by Food Agriculture Organization (FAO). This was done to check if the Great Usuthu River water quality was within international water quality guidelines for domestic and irrigation. Since the study area only contains two major food industries i.e. sugar and ethanol industries, only category 3 industrial water quality guidelines were used in the analysis for suitability of the water for industrial water supply (DWAF, 1996). The percentage exceedance was used to compare the results and the different guidelines or standards. This was done using the rank function in Microsoft Excel. The percentage sample over the limit (% exceedance) was the quantity of samples that have exceeded the confines as per the specified water quality standard or guideline.

CHAPTER FIVE: RESULTS AND DISCUSSIONS

5.1. Great Usuthu River spatial and temporal water quality and pollution load variation

Table 5.1 shows the summary statistics for the water quality measurements of the river water during the study period. The Repeated Measurements Analysis of Variance (ANOVA) results are shown in Appendix 5.

Table 5.1: Summary statistics for GUR water from 7 January to 29 March 2016.

Water Quality Parameters	N	Range	Min	Max	Mean	CV	Variance
Temperature	36	10.70	22.50	33.20	27.29	0.07	3.70
pH	36	1.17	7.36	8.53	7.87	0.03	0.10
EC	36	1157.10	86.90	1244.00	320.87	0.68	47173.80
DO	35	42.50	20.00	42.51	30.23	0.05	2.10
BOD	36	12.00	0.00	12.00	3.43	0.35	1.50
E.coli	35	1733.00	65.00	1733.00	558.88	0.27	23531.10
TC	36	1808.00	172.00	1980.00	925.87	0.32	89427.60
TA	36	24.99	0.01	25.00	10.39	0.11	1.40
TH	36	54.00	32.00	86.00	43.44	0.15	41.60
Chlorides	36	24.10	0.90	25.00	9.34	0.56	26.90
Nitrates	36	76.53	0.11	76.64	12.78	0.52	44.30
Colour	36	1405.00	60.00	1465.00	386.67	0.40	23677.60

5.1.1. Spatial and temporal variation of temperature

Figure 5.1.1 shows the spatial and temporal trend for the means of temperature measurement taken during the study. From Table 5.1, temperature ranged from 22.5 ^{o}C to 33.2 ^{o}C during the research period for all sampling points. The average temperature was 27.3 ^{o}C. The Coefficient of Variation (CV) for temperature was 0.07 which clearly shows that there was variation in temperature measurements (CV > 0).

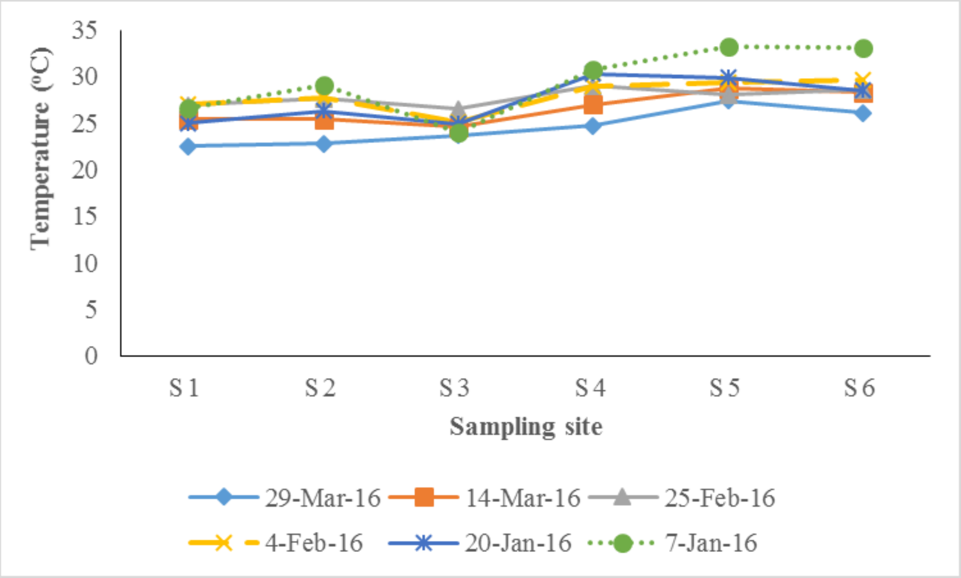


Figure 5.1.1. Spatio-temporal variation of temperature.

The spatial trend shows that temperature increased as you go downstream with Site 3 recording the least and Site 5 recording maximum. Site 3 recorded the least because it is a tributary to the Great Usuthu River (Mhlathuzane River) and captures water discharged from the Lubovane Dam. The temperature of the water could be influenced by the thermal stratification in the Lubovane dam and the time of sampling. Samples were collected between 0730hrs and 1100hrs on each sampling compaign. This observation is supported by Baldwin *et al.* (2009) who stated that dams affect the river system below the dam, changing characteristics such as temperature, flow and morphology. The temporal variation of temperature also shows a decreasing trend with the highest recorded in January and lowest towards the end of March 2016 in all sites. This was probably due to the approaching of winter. A study by Kumar *et al.* (2011) on the periodic variation of physicochemical water quality parameters for Sabarmati River and Kharicut canal at Ahmedabad (Gujarat) revealed a similar pattern. The ANOVA results (Appendix 5) show that there was significant spatiotemporal variation in the temperature measurements for the Great Usuthu River measured during the sampling period as $p<0.05$ ($p=0.044$). The time of sampling and sampling days might have led to fluctuations in water temperature as the weather changed.

5.1.2. Spatial and temporal variation of pH.

The pH values ranged from 7.36 to 8.53 and the mean was 7.9 during the period of the study at all the sampling sites along the river. The CV for pH 0.03 as shown in Table 5.1. The variations between sites and sampling sessions in pH measurements taken during the sampling period is summarized in Figure 5.1.2.

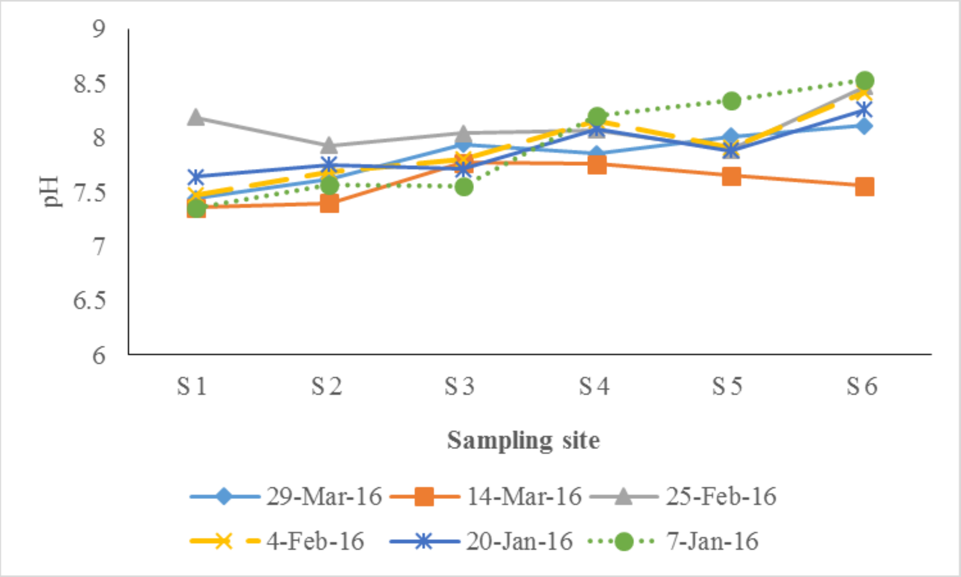


Figure 5.1.2. Spatio-temporal variation of pH

ANOVA results (Appendix 5) for pH also indicated significant spatiotemporal variations in the values of pH measured during the sampling period as $p<0.005$ ($p=0.047$). There was positive correlation with pH and temperature, as this has been proved in this study that the higher the water temperature, the higher the pH. A study by Charkhabi and Sakizadeh (2006) also observed that as temperature changes, pH changes as well and impacts on dissolved oxygen which affects biochemical and chemical reactions in the water such as photosynthesis, oxidation, nitrification and denitrification.

5.1.3. Spatial and temporal variation of electrical conductivity.

Figure 5.2.4 presents the spatiotemporal variations in the means for Electrical Conductivity (EC) measurements taken in the Great Usuthu River during the study period. From Table 5.1, EC mean values were in the range 86.9 µS/cm – 1244.0 µS/cm and the mean was 320.9 µS/cm. The CV for EC measurements was 0.68 as shown in Table 5.1.

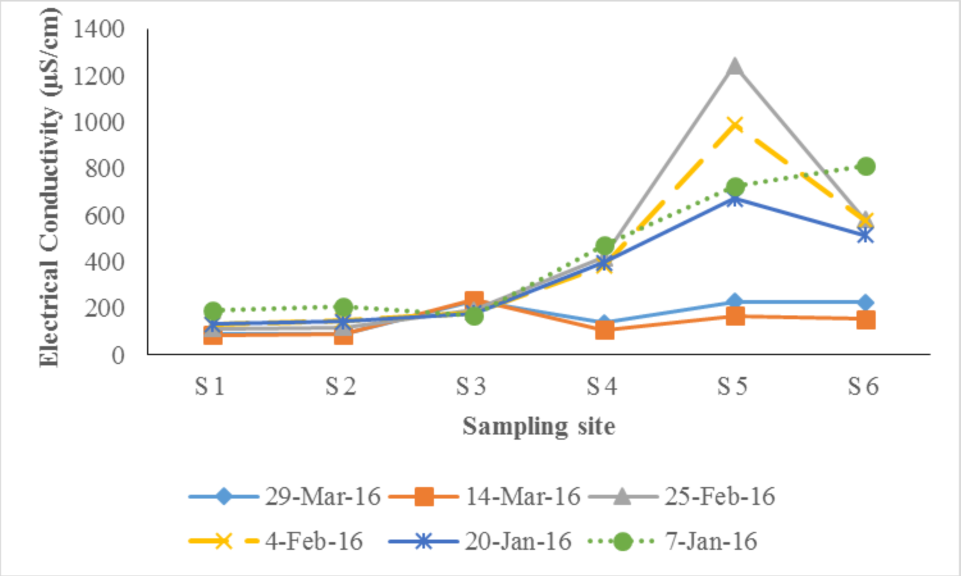


Figure 5.1.3. Spatio-temporal variation of electrical conductivity.

There was generally an increasing trend in terms of EC spatially and a relatively decreasing trend temporally as shown in Figure 5.1.3. The decreasing temporal trend is due to the approaching winter which led to reduced water temperature which consequently results in reduced EC in the water. A study by Kumar *et al*, (2011) on the assessment of seasonal variation and water quality Index of Sabarmati River and Kharicut canal at Ahmedabad, Gujarat also came up with a similar observation. The ANOVA results (Appendix 5) for EC also indicated statistically significant spatial and temporal variation in EC measurements as $p<0.005$ ($p=0.017$). The significant variation in electrical conductivity could also be attributed to several factors such as the time of sampling, the chemical reactions in the water and the water temperature. High values of electrical conductivity in the water mean that there could be higher levels of TDS and TSS in the water or industrial wastewater discharge containing metal ions (Charkhabi and Sakizadeh, 2006). Site 5 and Site 6 were situated adjacent to the USA Distillers factory and Ubombo Sugar Mill wastewater discharge points on the river and these had higher EC values compared to the other sites.

5.1.4. Spatial and temporal variation of dissolved oxygen

The Dissolved Oxygen (DO) concentration values ranged from 20.0 % saturation to 42.5 % saturation and a mean of 30.2 % saturation was observed during the study period for all the sampling sites along the river as shown in Table 5.1. The CV for DO was 0.05. The DO spatiotemporal variation for the Great Usuthu River for periods from January 2016 to March 2016 is shown in Figure 5.1.4.

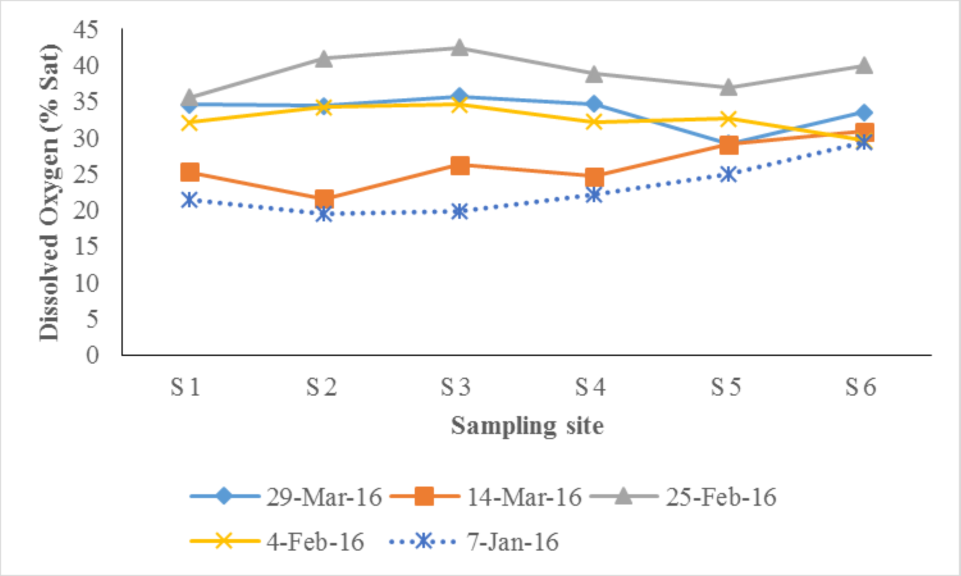


Figure 5.1.4. Spatio-temporal variation of dissolved oxygen.

From the ANOVA results (Appendix 5) for DO measurements taken during the study period, there was significant spatiotemporal variation in the DO concentration values across the sampling sites and sampling campaigns. This was evident by the fact that the $p = 0.034$ ($p<0.05$). Figure 5.1.4 shows the spatial and temporal DO (% saturation) variation during the study period. The DO was not successfully analyzed on 20 January 2016 due to the Swaziland Water Services Corporation laboratory incompetence. However DO was analyzed successfully on five sampling campaigns. Dissolved Oxygen is important to the health of a river as it is a critical necessity for the living organisms such as fish, turtles, and other aquatic life inhabiting the River. Changes in oxygen concentration can affect certain species reliant on oxygen-rich water, disrupting the food chain. Dissolved Oxygen has been proven to be a useful indicator of water pollution and the effects of urbanization as clearing land and development may send excess organic matter into streams, which uses up oxygen during decomposition.

5.1.5. Spatial and temporal variation of Biological Oxygen Demand

From Table 5.1, Biological Oxygen Demand (BOD) ranged from 0.0 mg/l to 12.0 mg/l during the research period in all the sampling sites along the river. The mean BOD value was 3.4 mg/l during the sampling period for the sampling sites along the river. The CV for BOD was 0.35. Figure 5.1.6 shows the spatiotemporal variations in BOD values for the Great Usuthu River during the sampling period.

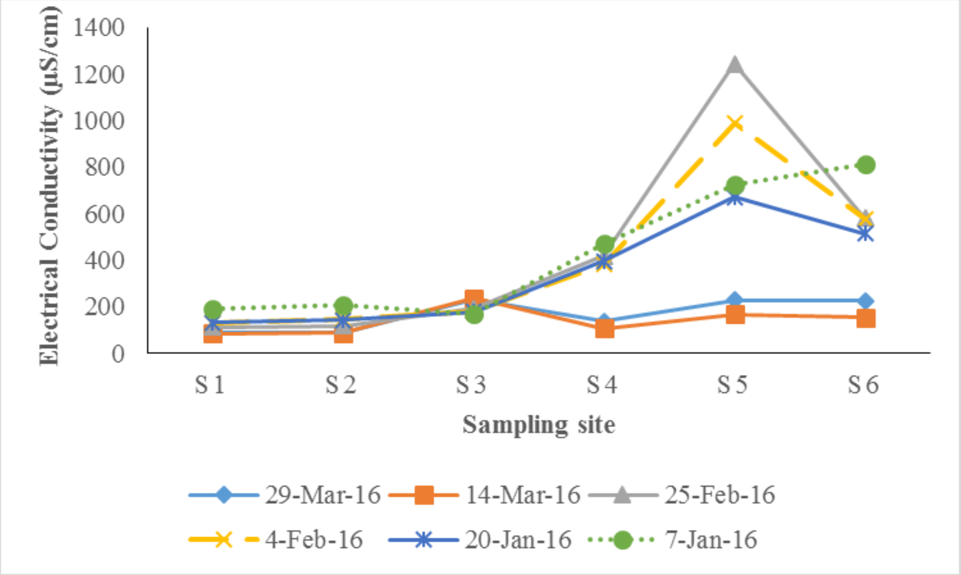


Figure 5.1.5. Spatio-temporal variation of biological oxygen demand.

From the ANOVA results (Appendix 5) for BOD measurements taken during the study period, there was statistically significant spatiotemporal variation in the BOD concentration values during the sampling period as p = 0.042 ($p<0.05$). The decrease in the BOD was probably due to the river dilution due to rains, river natural purification and increase in BOD was during low river flow periods. The improved water quality at Site 4, 5 and 6 revealed the self- purification capacity of the river (Kannel *et al.*, 2008). A study by Kuyeli et al, (2009) indicated that increase in BOD values in river water is associated with low river discharge rate, leachates from solid wastes dumps and runoff from catchment containing organic substances. However during rainfall and river agitation, there was a rise in the DO concentration, thus causing a decline in BOD.

5.1.6. Spatial and temporal variation of Escherichia Coli.

From Table 5.1, *Escherichia Coli* (E.coli) ranged from 65.0 MPN/100ml to 1733 MPN/100ml during the research period in all the sampling sites along the river. The mean *Escherichia Coli* concentration was 558.9 MPN/100ml during the research period for the sampling sites. The CV for E.coli measurements was 0.27. Figure 5.1.6 shows the spatial and temporal variations for E.coli measurements from the water samples from all the sampling sites along the river during the sampling period.

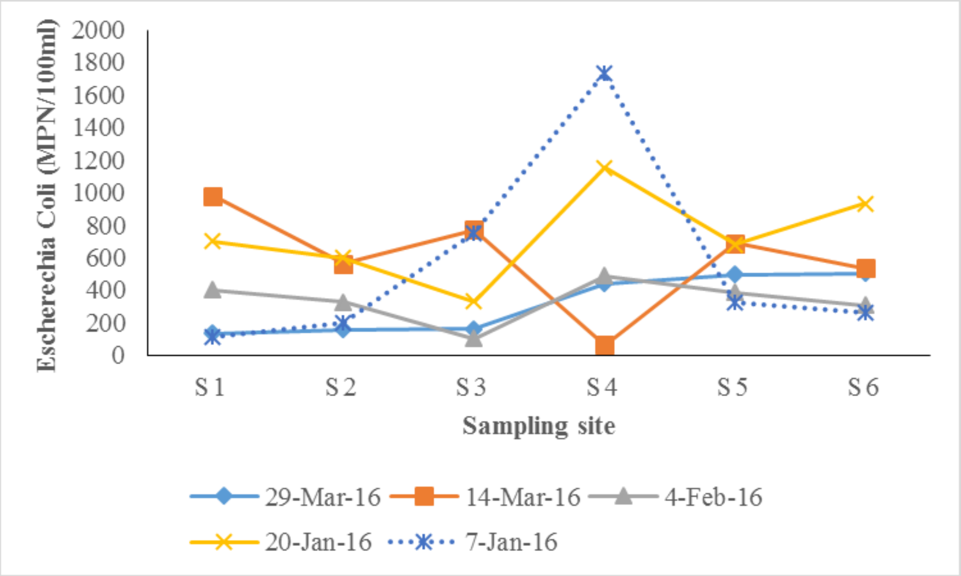


Figure 5.1.6. Spatio-temporal variation of E.coli.

From the ANOVA results (Appendix 5) for E.coli measurements taken during the study, there was statistically significant variation in the E.coli concentration values across all sampling sites and sampling campaigns as p = 0.007 (p<0.05). Generally, the E.coli concentration was high in all six sites sampled (Figure 5.1.6). Site 4 had the most extreme E.coli concentration on 7 January 2016. The high E.coli concentration in the river water is attributed to the poor sanitation present in the area together with the open defecation that could currently being practiced especially at

Mndobandoba. The decreasing trend is due to the rainfall received which might have resulted in significant dilution of the river water. E.coli was not analyzed on 25 February 2016 due to the Swaziland Water Services Corporation laboratory incompetence. According to Manyatsi and Tfwala (2012), in the study conducted on Velezizweni community in Swaziland, high E.coli and Streptococci (> 10 CFU/100ml) was detected in river and piped water. This made the community vulnerable to water borne diseases as they depended on piped water and river water (Manyatsi and Tfwala, 2012). It can therefore be concluded from the findings that the people using the river water directly without treatment in the study area are vulnerable to water borne diseases such as diarrhea.

5.1.7. Spatial and temporal variation of total coliforms

From Table 5.1, the Total Coliforms (TC) concentration ranged from 172.0 CFU/100ml to 1980.0 CFU/100ml during the research period in all the sampling sites along the river. The mean TC concentration was 925.9 CFU/100ml for the sampling sites along the river during the sampling period. The CV for TC measurements was 0.32. The spatiotemporal variation in TC concentrations during sampling period is presented in Figure 5.1.7.

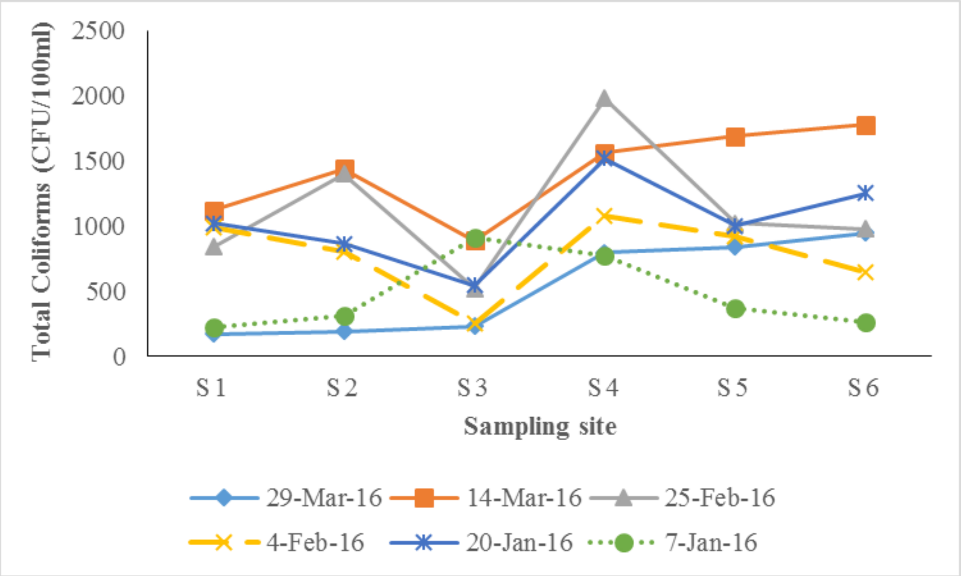


Figure 5.1.7. Spatio-temporal variation of total coliforms.

From the ANOVA results (Appendix 5), there was statistically no significant spatiotemporal variation in the TC concentration values during the sampling period as p = 0.656 (p>0.05). Generally, the TC concentration was high in all six sites sampled with Site 3 having the least. Again, Site 4 had the most extreme TC concentration. The study area has many scatted settlements and livestock is common. Combined with open defecation, poor sanitation, livestock droppings, runoff from feedlots and agricultural plantations, these are the influences that might be accountable for the elevated total coliform levels. This could be attributed to faecal coliforms from livestock and other faecal material deposited by runoff into the river. Cattle make up the largest part of the livestock population of the basin, followed by sheep and goats. The highest concentrations of livestock are found in the Middleveld region of the Ngwavuma catchment, and in the Usuthu catchment to the west of Maloma. The livestock population of the basin is estimated to be around 900 000 equivalent large stock units. Also taking note that there could be other sources upstream Site 1 as high concentration was also observed in Site 1. Presence of TC at high quantities in water indicates occurrence of disease organisms in the water, therefore well-being dangers to humans is compromised (Charkhabi and Sakizadeh, 2006).

5.1.8. Spatial and temporal variation of total alkalinity.

Total Alkalinity (TA) concentration was in the range 0.01 mg/l – 25.00 mg/l during the research period in all 6 sampling sites along the river as shown in Table 5.1. The mean TA concentration was 10.4 mg/l during the research period for the sampling sites along the river. The CV for TA measurements was 0.11. Figure 5.1.8 shows the differences of TA concentration between the sampling sites and sampling sessions.

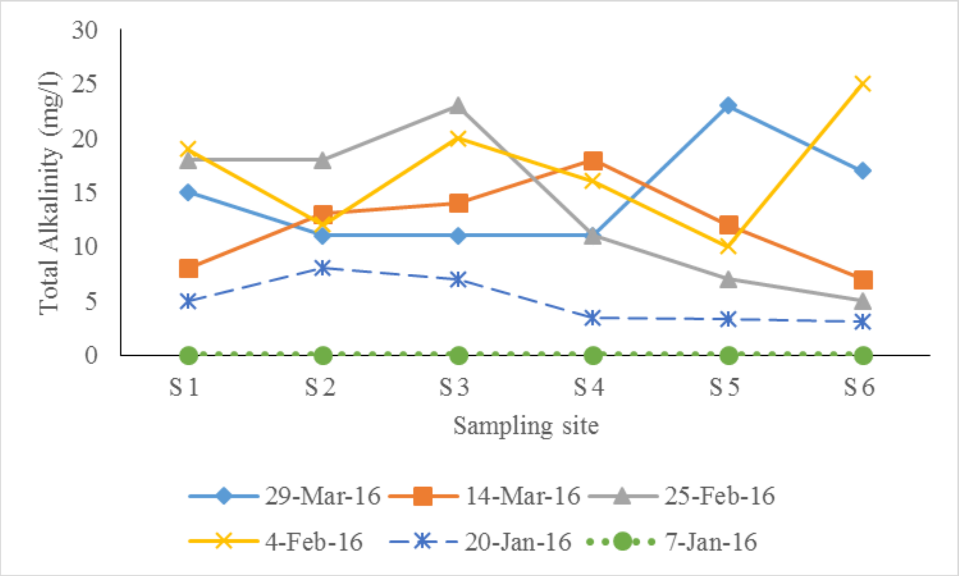


Figure 5.1.8. Spatio-temporal variation of total alkalinity.

It can be deduced from Figure 5.1.9 that generally the TA followed a decreasing spatial trend from upstream sites to down scream sites (except Site 3 being a tributary). The temporal trend shows that TA of the river water increased reaching peak on the 4 February 2016 thereby decreasing on ward. From the ANOVA results (Appendix 5), there was statistically significant variation in the TA concentration values across sampling sites and campaigns as $p = 0.001$ ($p<0.05$). Generally the TA concentration varied spatially and temporally during the study period. Mts *et al*, (2010) indicated that differences between sites and sampling campaigns for TA measurements are influenced by river flow and amount of pollutants draining into the river from the catchment.

5.1.9. Spatial and temporal variation of total hardness (as $CaCO_3$)

The Total Hardness (TH) ranged from 32.0 mg/l to 86.0 mg/l for the sampling sites along Great Usuthu River during the research period as shown in Table 5.1. The mean TH was 43.4 mg/l and CV was 0.15 for all the sampling sites. Figure 5.1.9 shows the spatial and temporal variation for total hardness along the river.

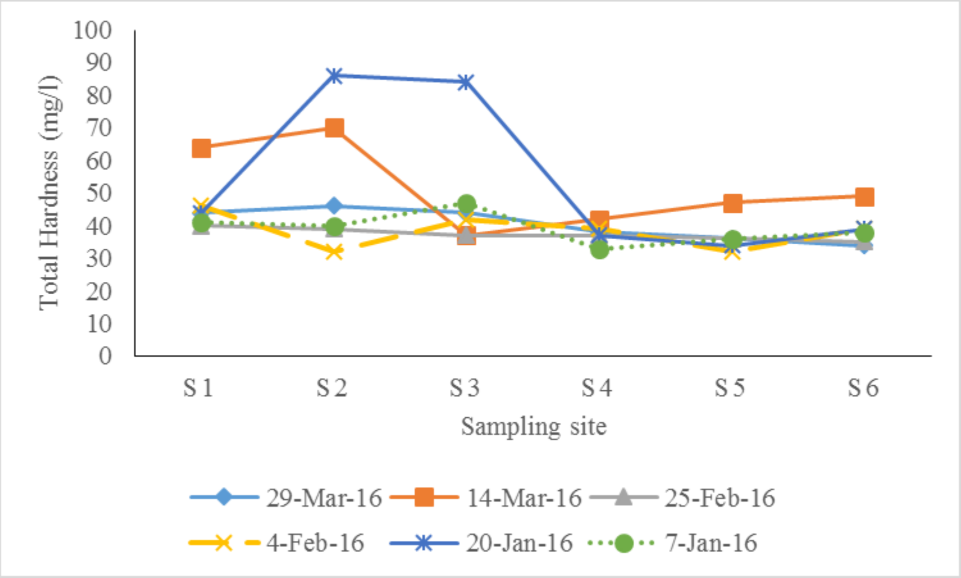


Figure 5.1.9. Spatio-temporal variation of total hardness.

Generally, TH concentration increased from Site 1 to Site 2 then decreased up to site 5 thereby increasing slightly to Site 6 as shown in Figure 5.1.9. From the ANOVA results (Appendix 5) there was also statistically significant spatiotemporal variation in TH concentration values measured during the sampling period as p = 0.00 ($p<0.05$). Generally the TH concentration was high at the upstream sites (Sites 1, 2 and 3). Sites 4, 5 and 6 had the least.

5.1.10. Spatial and temporal variation of chloride.

Chloride concentration was in the range 0.9 mg/l- 25.0 mg/l for all the sampling sites. The mean chloride concentration was 9.3 mg/l and the CV was 0.56 as shown in Table 5.1. Figure 5.1.10 shows the chloride concentration variations between sampling sites and sampling sessions along the river during the study period.

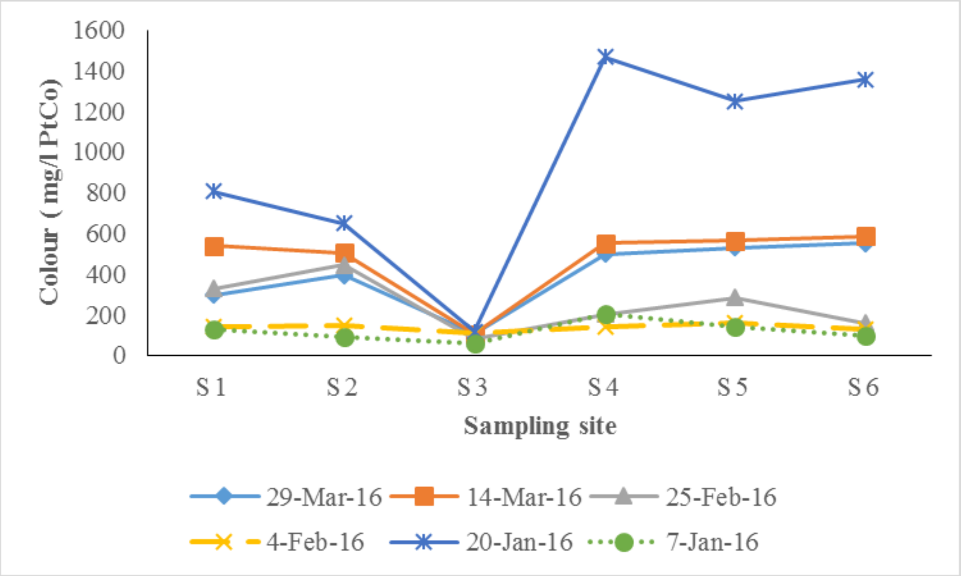


Figure 5.1.10. Spatio-temporal variation of chloride.

From the ANOVA results, there was statistically significant spatiotemporal variation in the means for chlorides concentration values during sampling period. This is evident due to the fact that the p = 0.000 ($p<0.05$). Generally the chloride concentration increased as you go downstream the river and decreased temporally. From Figure 5.1.10, higher chloride concentrations were measured on 20 January 2016. The lower concentrations on the other sampling sessions were due to dilution from runoff as rainfall was received. The high concentration could be linked to washing clothes, discharge of domestic waste into the river, industrial wastewater discharge, surface runoff and decrease temporally could be due to the rains having a dilution effect on the river water quality. Similarly, Zhang *et al.*, (2010) on the river water pollution control in the Xiangjiang River indicated that chlorides levels in river water are influenced by the amount of domestic waste discharged into the river and industrial wastewater discharge. The pollution load of the river was found to be in the range 0.2 tons/day – 8.8 tons/day for chloride.

5.1.11. Spatial and temporal variation of nitrates

Average nitrates levels were in the range 0.11 mg/l – 76.64 mg/l for all sampling sites during the study period. The mean nitrates concentration was 12.8 mg/l and the CV was 0.52. Figure 5.1.11

show the spatial and temporal variation of the average values for nitrates measurements taken between the periods 7 January 2016 to 29 March 2016 for the Great Usuthu River.

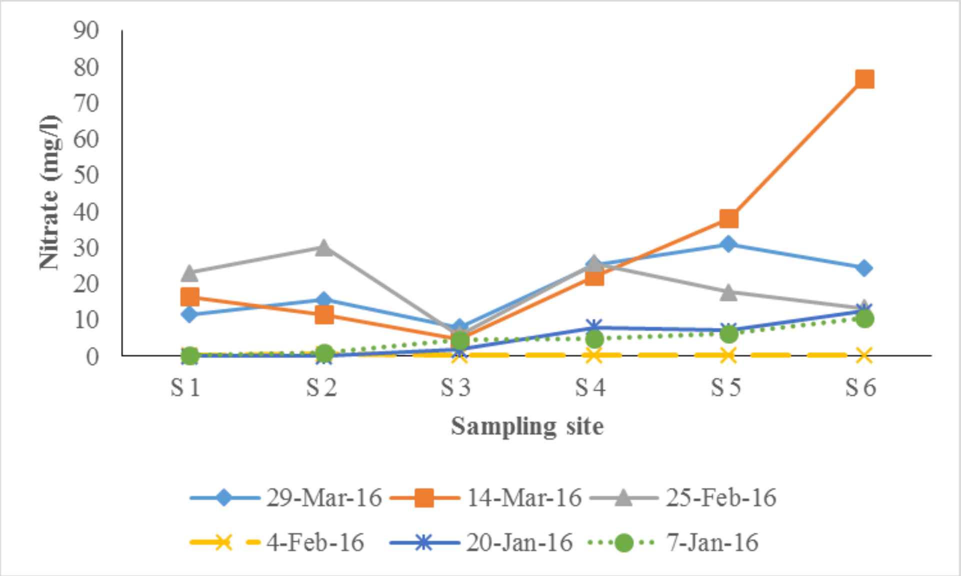


Figure 5.1.11. Spatio-temporal variation of nitrates

The spatial trend shows that the nitrates concentration increased from upstream site to downstream with Site 6 recording the highest value. The temporal trend also shows rise in nitrates concentration in the river with highest obtained mid-March 2016. This is attributed to the presence of the agricultural activities such as dense sugarcane irrigation as you go downstream the river and also the impacts of the rains received. The basin has formal irrigation schemes that have been established for smallholder farmers totaling to about 16 000 ha in Lower Usuthu Small Holder Irrigation Project and commercial irrigation totaling to 18 500 ha for Ubombo Sugar. A study by Sankar *et al.* (2009) indicated that high nitrates levels in the water are due to organic materials collected from agricultural catchments during the rainy season. From the ANOVA results in Appendix 5, there was significant spatiotemporal variation in the nitrates concentration values across sampling sites and campaigns as p = 0.001 ($p<0.05$). The concentration of nitrates in a river depends on agricultural activities particularly application of nutrients in the catchment which eventually find its way to the river through leaching (Bu *et al*. 2010). Therefore this suggest that the dense commercial agriculture, particularly dense sugarcane irrigation, is responsible for the high mean nitrates concentration values observed during the study period especially at the downstream sites.

5.1.12. Spatial and temporal variation of colour

The colour measurements ranged from 60.0 mg/l PtCo to1465.0 mg/l PtCo for the sampling sites along the Great Usuthu River during the study period. The mean colour measurement was 386.7 mg/l PtCo and CV was 0.40. The spatial and temporal variation of colour measurements for the six sampling sites along the Great Usuthu River are shown in Figure 5.1.12.

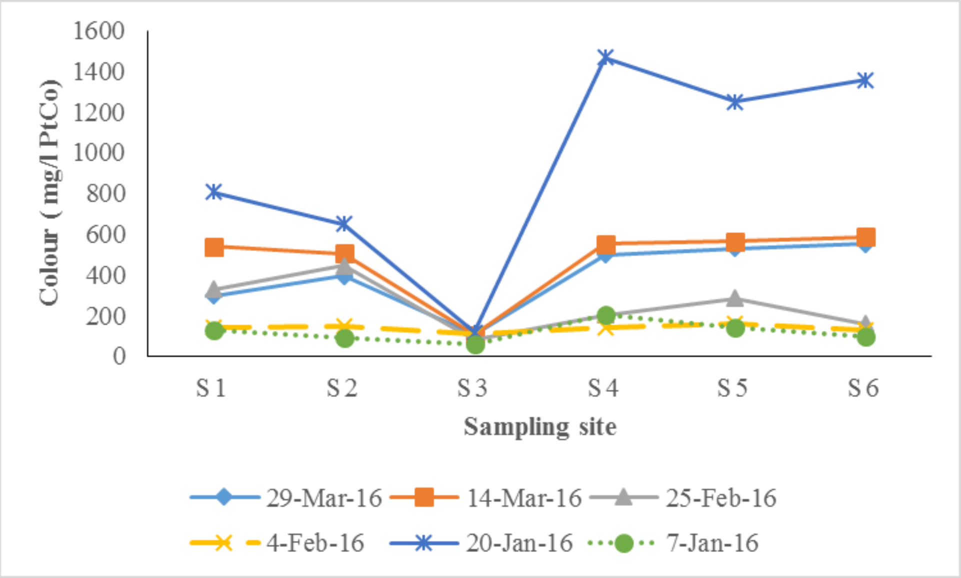


Figure 5.1.12. Spatio-temporal variation of colour.

The graph shows that Site 3 had the lowest mean colour measurement values when matched to the other points. Site 4 had peak mean colour measurement. Taking into account that Site 3 was located at the Mhlathuzane River, there was generally an increase in the mean colour measurement from Site 2 to Site 4 and then a decrease from Site 4 to Site 6. From the ANOVA results (Appendix 5) for colour measurements, the spatial and temporal variation for colour measurements values across the sampling sites and campaigns was statistically significant. This was evident by the fact that the p = 0.000 ($p<0.05$). Increasing colour concentrations along the river from the upstream sites suggested the possibility of contribution by agricultural, rural and urban activities in this area and also agricultural and industrial activities on the downstream sites

(Site 5 and 6). This was supported by Abowei *et al.*, (2010) who concluded that rivers tend to collect solid and liquid waste from catchment land during rainy season and this result in high values for turbidity and colour measurements. Highest concentrations were linked to land use activities and geological nature of the area where by surface water is contaminated via base flow (Roy *et al.,* 2014).

5.1.13 Spatial and temporal variation of pollution load in the Great Usuthu River.

Assessment of pollution load in tonnes per day at different locations along the river was done using the Source Monitoring Method developed by EPA (2009). This was only done for only 3 sites due to the non-availability of the current meter to measure river flow rate on the other sites during the six sampling campaigns. The pollutant loading rates were computed for Biological Oxygen Demand (BOD), chloride, nitrates and Total Dissolved Solids (TDS) as they were the only parameters out of the 12 that were eligible for computation of loads. TDS concentration was derived using a factor of 0.8 from electrical conductivity. The river flow rate recorded at the different gauging stations varied over the entire sampling period. For gauging station 6 (Site 2), river flow rate ranged from 0.6 m^3/s to 46.1 m^3/s and for gauging station 16 (Site 6), the river flow rate ranged from 0.09 m^3/s to 6.2 m^3/s. The variations are due to the rainfall received which affected the river flow rate (see Appendix 6) during the sampling period and the river water abstraction rate by the farmers, water utility companies and industries in the river basin. The river flow rate recorded for gauging station 19 (Site 3) ranged from 0.51 m^3/s to 3.9 m^3/s. This varied due to the discharge rate from the Lubovane Reservoir which depends on reservoir quality and water demand.

Figure 5.1.13.1 shows the temporal variation for pollution load estimates measured at Site 2. The temporal trend for all the parameters followed a similar trend to that of the river flow rate recorded at gauging station 6.

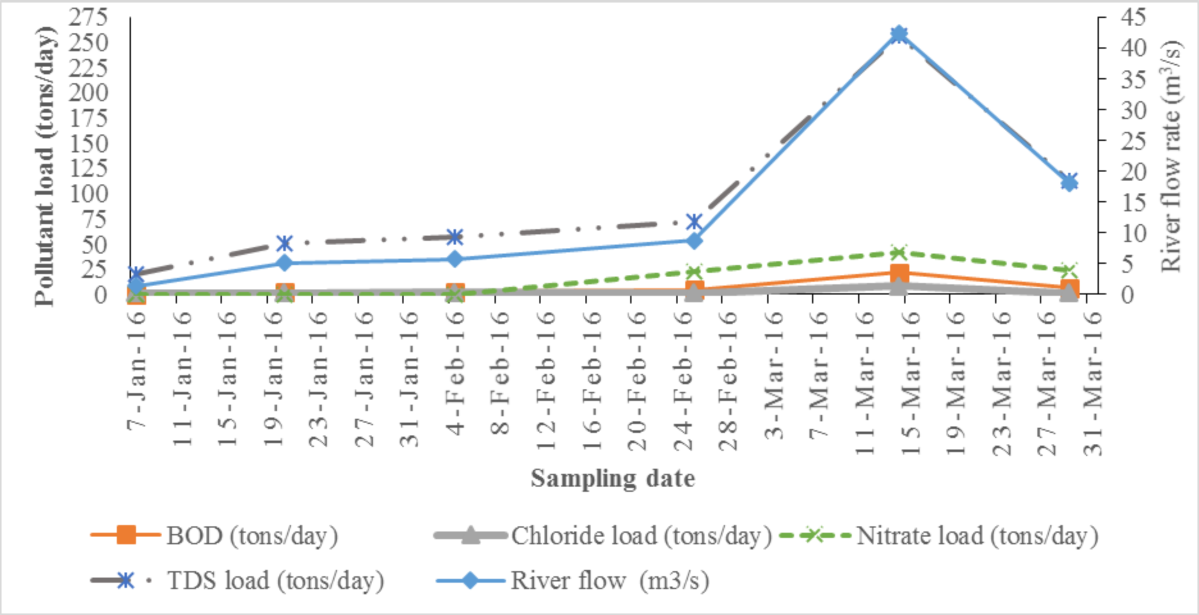


Figure 5.1.13.1 Site 2 pollution load estimates for Great Usuthu River (January to March, 2016

From Figure 5.1.13.1, the BOD load was in the range 0.2 tons/day to 22.0 tons/day. Chloride load was in the range 1.3 tons/day – 8.8 tons/day and nitrate load was in the range 0.01 tons/day – 42.1 tons/day. The TDS load for Site 2 ranged from 20.6 tons/day to 256.4 tons/day. Highest values were recorded mid-March as shown in Figure 5.1.13.1. Located adjacent to Site 2, are the Siphofaneni Dip tanks, Manzana hot springs and Siphofaneni Septic tank which discharge wastewater directly to the Great Usuthu River. The catchment activities and runoff together with flow from upstream influenced the pollution spatial and temporal variation during the study period. This is also supported by a study by Basu and Lokesh (2013) which indicated that differences in water quality depended on the natural and anthropogenic activities and the runoff generated within the catchment as they contribute significantly to the overall water quality status of a river or receiving waters.

Figure 5.1.13.2 shows the temporal variation for pollution load estimates measured at Site 3. The BOD load was in the range 0.1 tons/day to 0.3 tons/day. Chloride load was in the range 0.01 tons/day – 2.0 tons/day and nitrate load was in the range 0.01 tons/day – 1.4 tons/day. The TDS load for Site 3 ranged from 6.3 tons/day to 39.2 tons/day.

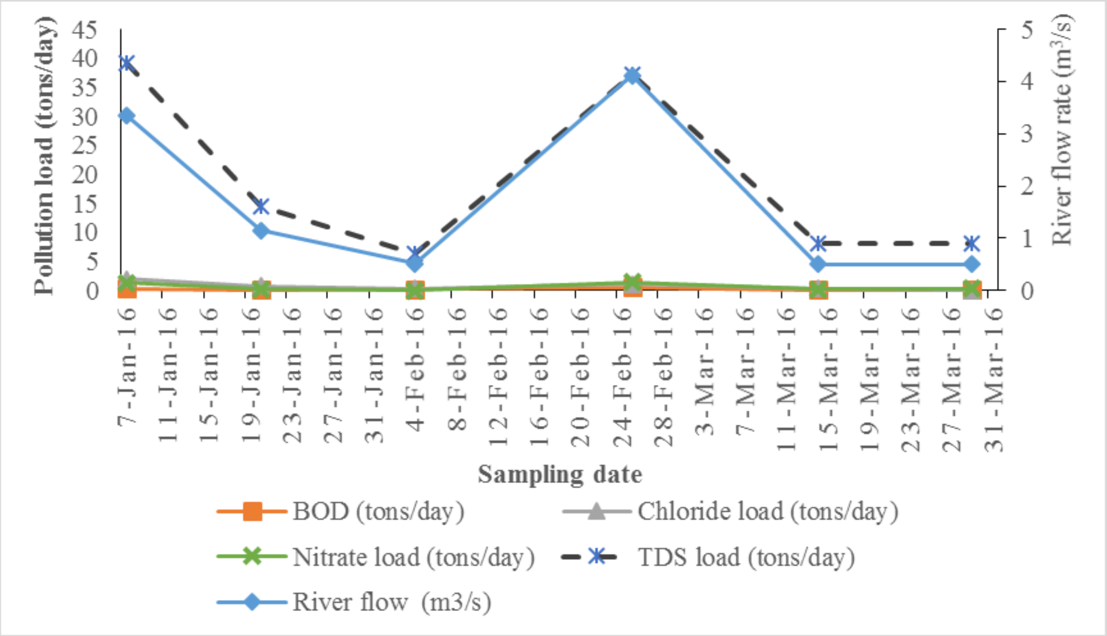


Figure 5.1.13.2 Site 3 pollution load estimates for Great Usuthu River (January to March, 2016

The pollution load estimates for Site 6 are shown in Figure 5.1.13.3. The BOD load was in the range 0.1 tons/day to 1.8 tons/day. Chloride load was in the range 0.2 tons/day – 8.1 tons/day and nitrate load was in the range 0.1 tons/day – 30.4 tons/day. The TDS load for Site 6 ranged from 5.1 tons/day to 199.9 tons/day. Site 6 is located downstream of the Ubombo Sugarmill wastewater discharge point and surrounded with sugarcane plantations and forests.

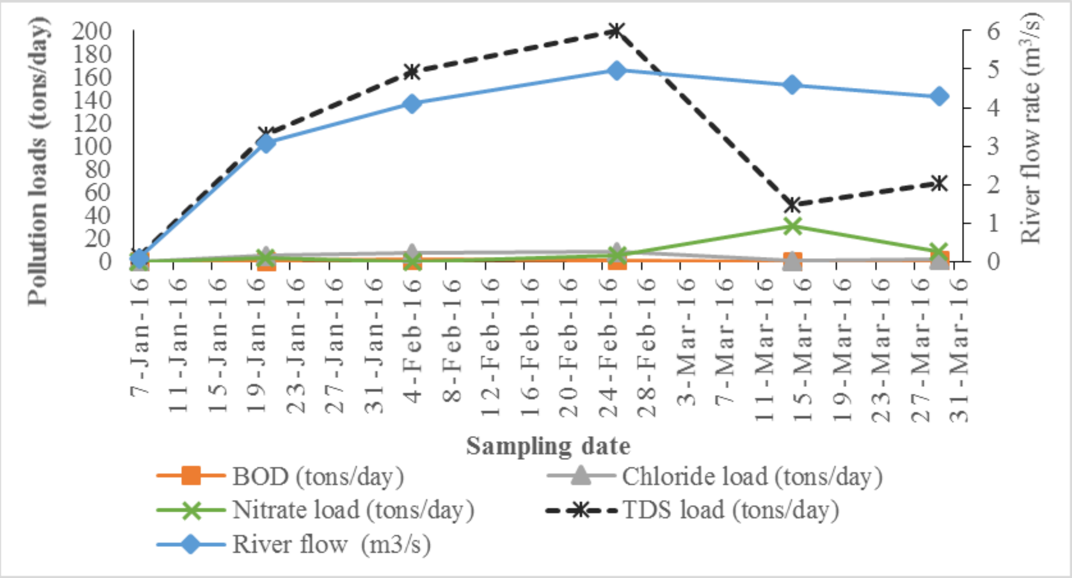


Figure 5.1.13.3 Site 6 pollution load estimate for Great Usuthu River (January to March, 2016

The pollution loads for Site 6 also followed the river flow trend indicating the impact of runoff from the catchment.A study by Sadhana and Raj (2013) came up with similar observation in the pollution load assessment of the Mandakini River in India. The study concluded that higher pollution load (greater than 2.0 tons/day TDS) was mainly due to runoff from the catchment and discharge of untreated wastewater from industries directly into the river.

As a summary, the pollution load estimate results indicate that Site 2 was the most polluted as it had highest pollution loads for all 4 parameters compared to Site 2 and 6. Site 3 was the least polluted compared Site 2 and 3 and this is probably due to the less concentration of the parameters and lower river flow measured at Site 3. The lower river flow rate was due to the controlled discharge rate from the Lubovane reservoir. The variations in pollution loads therefore makes assessing pollution loads on a regular basis important in order to estimate the contributions of pollution sources within the catchment.

5.2. Determination of the key water quality parameters and optimal sampling points

5.2.1 Determination of critical/key water quality parameters

Principal Component Analysis (PCA) was carried out to select the key water quality constituents. This was done to select the parameters which would provide more meaningful information of the whole dataset without significant loss of information (Gajbhiye *et al.*, 2015). The PCA was done using the XLSTAT 2016 software which uses Microsoft Excel. The results of the PCA including the eigenvalues and the contributions of the variables are shown in Figure 5.2.1 and Table 5.2.1.

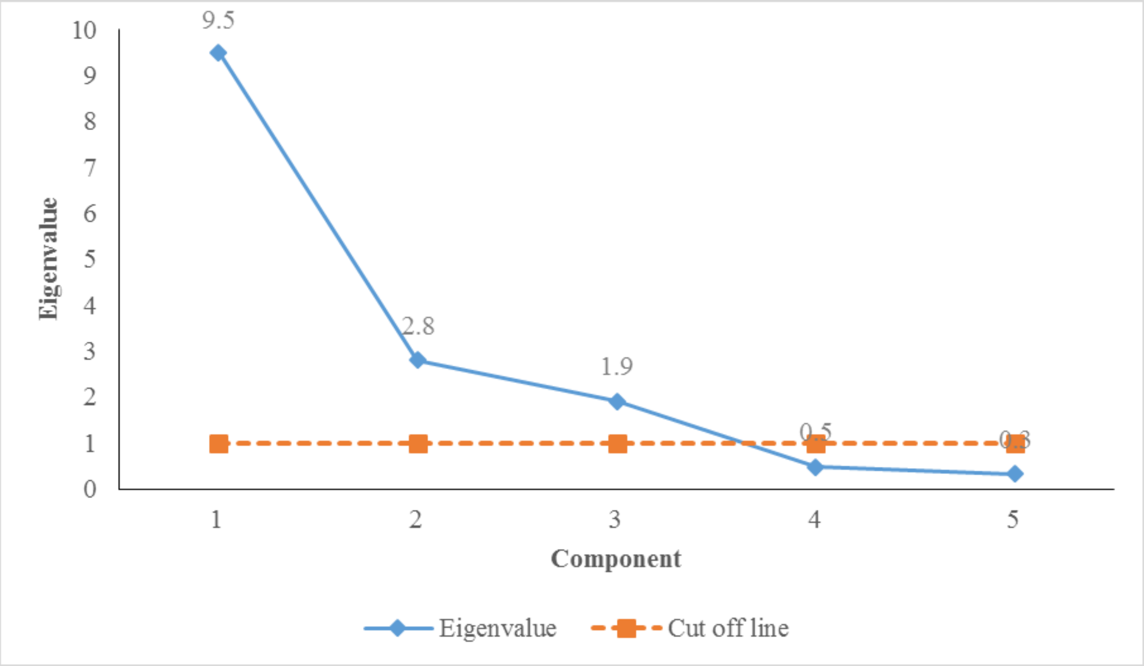


Figure 5.2.1. Principal component extraction

From the scree plot in Figure 5.2.1, only three principal components were selected out of the five established basing on their eigenvalues. These were component 1, 2 and 3 as they had eigenvalues greater than 1. According Gajbhiye *et al.* (2015), only principal components with eigenvalues greater than one can be used to assess the dominant variable that have more meaningful information to the variance in the whole dataset. Table 5.2.1 shows the contributions (loadings) of the water quality parameters (variables) per principal component to the overall variability of the whole dataset.

Table 5.2.1. Contribution of the variables (%)

Water Quality Parameters	Component 1	Component 2	Component 3
Temperature	0.002	0.002	0.102
pH	0.000	0.000	0.000
Electrical Conductivity	**10.359**	**80.366**	**1.450**
Dissolved Oxygen	0.000	0.003	0.041
Biological Oxygen Demand	0.000	0.002	**2.032**
Chemical Oxygen Demand	0.010	0.069	**4.450**
E.coli	**8.734**	**10.997**	**31.593**
Total Coliforms	**65.410**	**7.745**	**38.436**
Alkalinity	0.001	0.000	**6.060**
Hardness	0.019	0.020	**2.263**
Chlorides	0.008	0.032	**6.372**
Nitrates	0.017	0.025	0.750
Phosphates	0.000	0.000	**2.424**
Colour	**15.439**	**0.734**	**3.960**

From Table 5.2.1, Component 1 showed strong loading with total coliforms contributing 65.4%, colour (15.4%), electrical conductivity (10.4%) and E.coli contributing 8.7%. Component 2 showed electrical conductivity contributing 80.4 %, E.coli (11%), total coliforms (7.7%) and colour contributing 0.7%. Component 3 showed total coliforms (38.4%), E.coli (31.6%), chloride (6.4%), total alkalinity (6.1%), COD (4.5%), BOD (2.0%), total hardness (2.3%), phosphates (2.4%), colour (4.0%) and electrical conductivity (1.5%). Therefore the variance or substantial difference in water quality dataset was mainly due to the following parameters: electrical conductivity, total coliforms, E.coli and colour based on the parameters identified by all three principal components (factors). A study by Fataein (2011) on the evaluation of river water quality using PCA also identified electrical conductivity of one of the parameters that caused the substantial differences on surface water quality. Similarly, Gajbhiye et al (2015), established three principal components and electrical conductivity was amongst the principal water quality parameters established by the PCA conducted.

5.2.2. Determination of optimal water quality sampling points

Cluster Analysis was used to identify optimal sampling points within the study area using the results from the water quality assessment. The analysis of variance results revealed that there was statistically significant variation in water quality between the sampling sites and sampling sessions between January and March 2016. Hence there was a need to verify whether the water quality monitoring points that are used by the Government of Swaziland (Department of Water Affairs, Water Resources Branch) in the study area are adequate or not. Based on the 12 water quality variables, cluster analysis classified the six sampling sites into four distinct clusters. Table 5.2.2.1 shows the clusters analysis results from the k means grouping method in SPSS software version 23. The k means clustering algorithm which aims at partitioning n observations into *k* groups where each observation fits to the group with the closest average, serving as a model of the group (Fataei, 2011).

Table 5.2.2.1. Water quality characteristics for identified clusters.

Water Quality Parameters	**Cluster**			
	1	**2**	**3**	**4**
Temperature	26.0	29.2	24.8	28.4
pH	7.6	8.1	7.8	8.0
Electrical Conductivity	128.9	574.6	198.8	319.3
Dissolved Oxygen	28.9	31.7	30.8	29.5
Biological Oxygen Demand	4.9	2.5	2.4	3.4
Escherichia coli	486.6	515.8	489.0	859.5
Total Coliforms	861.3	993.4	463.6	1382.2
Total Alkalininty	10.6	9.4	12.5	9.9
Total Hardness (as $CACO_3$)	49.3	37.9	48.5	37.7
Chloride	3.9	15.0	6.8	11.3
Nitrates	9.2	19.9	4.2	14.4
Colour	372.8	483.4	97.0	510.5
Average Linkage (Between Groups)	1	4	2	3
Average Linkage (Between Groups)	1	1	2	3

This suggests that based on the similarities of the variables, there should be a minimum of 4 monitored sampling points in the Great Usuthu River within the study area. Site 2 and Site 6 are the same sampling sites that are used by the Government of Swaziland (DWA) on the water quality monitoring of the GUR.

Table 5.2.2.2. Cluster Membership results using the k means clustering algorithm.

Case Number	Sampling Site	Cluster	Distance
1	1.0	1	88.939
2	2.0	1	88.939
3	3.0	3	.000
4	4.0	4	.000
5	5.0	2	96.924
6	6.0	2	96.924

From Table 5.2.2.2, Cluster 1 is formed by Site 1 and 2. Cluster 2 is formed by Site 5 and 6. Cluster 3 is formed by Site 3 and lastly Cluster 4 is formed by Site 4. According to Fataei (2011), the number of clusters identified using the k means clustering algorithm is the minimum number of points required to capture water quality status in a given catmint. This therefore means there is a need for a minimum of 4 key water quality monitoring stations in the study area. The Cluster Analysis (CA) outcomes show that the 2 water quality monitoring points currently in place were inadequate, therefore there is a need to add more water quality monitoring stations. The recommended locations for the additional water quality monitoring stations are Site 3 (Madlenya) and Site 4 (Mndobandoba). This is because Site 3 can be used to capture the tributary impacts (Mhlathuzane River) to the Great Usuthu River as tributaries also contribute to the overall water quality of the main river. Site 4 can be used as an additional site to capture the impact the surrounding area (catchment) has on water quality of the river as it passes through it.

5.3. River water quality status assessment using DWQI.

The values of Dinius Water Quality Index (DWQI) for the Great Usuthu River (GUR) obtained between the periods 7 January 2016 and 29 March 2016 are shown in Appendix 7. Table 5.3.1 shows the average DWQI values for the 6 sites over the sampling period. The average sub index values for each parameter at each sampling site were calculated and results are shown in Table 5.3.1. Sub index values were calculated using the sub index functions for each parameter as shown in Table 2.3.1.1.

Table 5.3.1: Average DWQI results for RWQ samples of the Great Usuthu River

Parameter	**Site 1**	**Site 2**	**Site 3**	**Site 4**	**Site 5**	**Site 6**
Temperature	1.2	1.2	1.2	1.2	1.2	1.2
pH	1.4	1.4	1.4	1.4	1.4	1.4
Electrical Conductivity	1.4	1.4	1.4	1.4	1.4	1.4
Biological Oxygen Demand	1.5	1.5	1.5	1.5	1.5	1.5
Dissolved Oxygen	1.4	1.5	1.5	1.5	1.5	1.5
Escherichia coli	1.5	1.5	1.5	1.4	1.5	1.5
Total Coliforms	1.4	1.4	1.5	1.4	1.4	1.4
Alkalinity	1.3	1.3	1.3	1.3	1.3	1.3
Hardness	1.4	1.4	1.3	1.4	1.4	1.4
Chlorides	1.5	1.5	1.5	1.5	1.4	1.5
Nitrates	1.6	1.6	1.5	1.5	1.5	1.5
Colour	1.3	1.3	1.3	1.3	1.3	1.3
DWQI	**59.9**	**58.2**	**59.6**	**52.7**	**53.8**	**54.6**
Water quality status category	**3**	**3**	**3**	**3**	**3**	**3**

From the DWQI results shown in Appendix 6, the DWQI was in the range 46.5 – 77.3 across sampling sites and sampling sessions. The higher values were obtained during the first sampling session and lower values on the other sampling sessions. This could have been due to catchment activities which could have altered parameter concentrations and also due to changes in river flow which influences the dilution capacity of the river (Chang, 2008). Figure 5.3 shows DWQI results compared to the DWQI water resource classification. The DWQI values for Site 1 was in the range 51.4 – 77.3 as shown in Appendix 6. Site 1 had an overall index of 59.9 as shown in Table

5.3.1 and Figure 5.3. The lower DWQI value could be due to possible pollution upstream sources which may include runoff from agricultural plantations at Sidvokodvo and surrounding areas and industrial effluent discharges at Matsapha. A study by Mnisi (2010) indicated that the Lusushwana River (a tributary to the Great Usuthu River) was indeed polluted and the major source of pollution was the Matsapha Industrial Site. The DWQI value for Site 2 was in the range 51.6 – 72.5 as shown in Appendix 6 during the sampling period and average DWQI value was 58.2. The DWQI values for Site 3 were in the range 53.6 – 62.3 as shown in Appendix 6 during the sampling period and average DWQI value was 59.6.

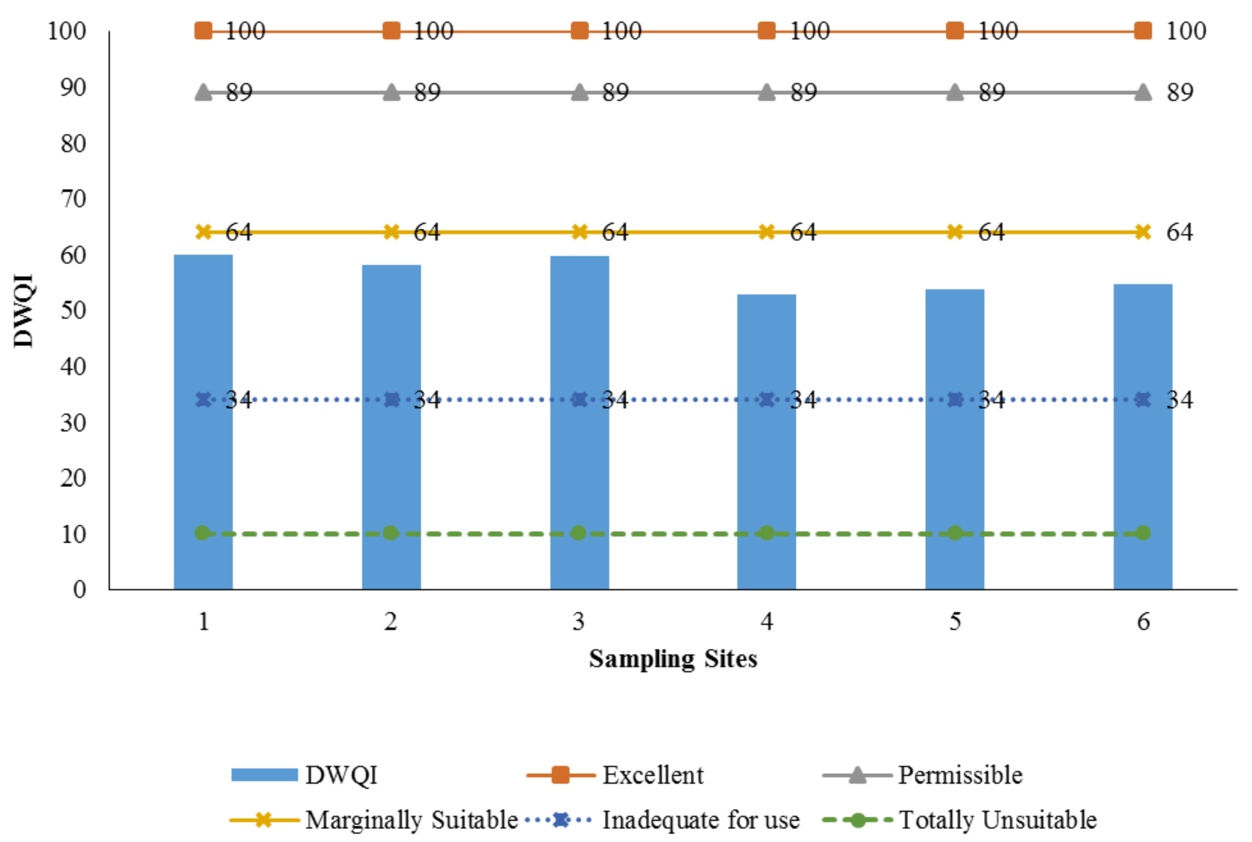


Figure 5.3: DWQI analytical results for the GUR for the period January to March 2016.

DWQI values for Site 4 during the sampling period were in the range 46.5 – 59.2 as shown in Appendix 7 and the average DWQI value was 52.7 as shown in Table 5.3.1 and Figure 5.3. The DWQI values for Site 5 ranged from 49.5 to 62.3 as presented in Appendix 6 during the sampling period. The average DWQI value for Site 5 was 53.8. DWQI values for Site 6 were in the range 49.4 – 62.3 during the sampling period as shown in Appendix 7 and the average DWQI value was 54.6. A study by Benvenuti et al. (2013) on the evaluation of water quality at the source of streams of the Sinos River Basin, southern Brazil also utilized the DWQI. The study showed that the DWQI revealed the doubtful quality in the three sampling sites studied as DWQI values were in the range 50 – 59 implying marginal water quality for public water supply, recreational, agricultural and industrial water uses. From the results as shown in Table 5.3.1 and Figure 5.3, it was concluded that the GUR water quality was in category 3 of the DWQI water resources classification implying that GUR quality status was marginally suitable for definite usages such as domestic supply, irrigation supply, recreation and industrial water use. Treatment of the water prior to use is recommended.

Similarly, the averages for water quality parameters during the study period were compared to local water quality guidelines as shown in Table 5.3.2. The results obtained were compared to the Swaziland Water Quality Objectives (SWQO) for surface water (see Appendix 1) to assess if the Great Usuthu River water quality met the national water quality limits for surface water. The water quality results were also compared with Swaziland Water Services Corporation guidelines for drinking water (see Appendix 8) since 37 907 people within the study area depended on the river water for domestic purposes (Dlamini *et al.*, 2014). The results were also compared to Irrigation and Category 3 Industrial water quality guidelines for South Africa (SAWQ) (see Appendix 9) to assess if the water quality met the local permissible limits for the irrigation and industrial water uses.

The findings were also compared to the irrigation water quality guidelines by the Food Agriculture Organization (FAO) and 2011 drinking water guidelines by World Health Organization (see Appendix 10 and 11 respectively). The comparison with the findings is shown in Appendix 12. This was done to assess if the Great Usuthu River water quality was still within international water quality limits for the domestic uses and irrigation. In the comparison, the percentage exceedance over the limit as prescribed by the different guidelines or standard was computed on a parameter per sample basis. This was done using the rank test in Microsoft Excel

2013 software.

From Table 5.3.2, according to the SWQO guidelines for surface water, the water quality for all sites sampled exceeded the SWQO limit in terms of DO, E.coli, TC and colour (100 % exceedance). Only 16.7 % of the samples above SWQO BOD limit of 5 mg/l (Site 2). For nitrates, only 50 % of the samples exceeded the SWQO nitrate limit of 10 mg/l (Site 4, 5, 6). According to the SWSC drinking water guidelines, all the samples exceeded the SWSC limit for E.coli, TC and colour (100 % exceedance). Only 16.7 % of the samples were above SWSC BOD limit of 5 mg/l (Site 2). For nitrates, only 50 % of the samples exceeded the SWSC nitrate limit of 10 mg/l (Site 4, 5, 6). According to the SAWQ for irrigation use, all the samples also exceeded the E.coli and TC limit of 1 CFU/100 ml. However this limit only applies to the irrigation of crops only to be consumed raw such as fruits and vegetable. The reason for this is to minimize the chances of human infection.

For industrial water use, only 16.7 % of the samples exceeded the SAWQ range of pH (6.0 – 8.0) (Site 6). All the other parameters met the SAWQ industrial use guideline. This therefore means the water quality for Sites 1 to Site 5 was suitable for category 3 industrial water use. All samples did not meet local surface, drinking and irrigation water quality guidelines. From Appendix 12, according to the WHO drinking water quality standards comparison, 50 % of the river water samples exceeded the EC limit of 250 µS/cm and Nitrates limit of 10 mg/l (Sites 4, 5, 6). All the sampling sites did not meet the E.coli and TC limit of 0 CFU/ 100 ml. According to the FAO irrigation water quality guidelines comparison, only 83.3 % of the samples exceeded the Nitrate limit of 5 mg/l (Sites 1, 2, 4, 5, 6). For irrigation water use, only the water quality for site 3 met the international water quality guideline (FAO). This therefore means the other sampling sites water quality was also not suitable for irrigation purposes according to the guidelines.

According to DWAF (1996), for water quality to be ideal for intended uses, the water quality should meet all the limits as stipulated by the specific water use guideline. Similarly a study by Sorlini *et al.* (2013) indicated that surface water resources in the Logone Valley (Chad-Cameroon) were highly microbial contaminated and not fit to be used for domestic and production purposes. But due to the non-availability of alternative water supply elevated levels of lead in public water supply, people opt to use river water which most of the time has high concentrations of total coliforms and Escherichia Coli. Khanna *et al*. (2013) also resolved that the Ganga River when compared to the WHO drinking water guidelines and ISO standards did not meet guideline values, hence the water was unsuitable for domestic purposes and can only be consumed after proper treatment.

From these results, it was concluded that the GUR water quality in most of the sampling sites was not suitable for domestic water uses, irrigation water uses for crops to be consumed raw and category 3 industrial water uses because not all the samples met all the water quality guideline limits as prescribed by the national and international guidelines. Similarly, the DWQI concluded that the GUR water quality was marginally suitable for domestic, recreational, agricultural and industrial water uses.

Table 5.3.2: Average GUR water quality analysis results and comparisons to local water quality guidelines

Sampling Sites	temp	pH	EC	DO	BOD	E.coli	TC	TA	TH	Chlorides	Nitrates	Colour
Site 1	25.6	7.6	125.7	29.8	4.3	390	728	10.8	46.5	3.9	8.6	373.3
Site 2	26.5	7.7	132.1	30.2	5.0	308	939	10.3	52.2	3.9	9.8	372.3
Site 3	24.8	7.8	198.8	31.8	2.5	353	487	12.5	48.5	6.8	4.2	97.0
Site 4	28.4	8.0	319.3	30.5	3.3	647	1388	9.9	37.7	11.3	14.4	510.5
Site 5	29.4	8.0	670.7	30.6	2.0	431	1095	9.2	36.8	15.4	16.8	488.0
Site 6	29.0	8.2	478.6	32.7	2.7	424	1122	9.5	39.0	14.7	23.0	478.8
SWQO	<35	6.5-8.5	<1800	> 48.7	< 5	10	10	NG	<1000	NG	<10	<20
% Sample>limit	0	0	0	**100**	**16.7**	**100**	**100**		0	0	**50**	**100**
SWSC Drinking	12–25	6.5-8.5	<1000	< 85	<5	0	0	<400	<200	<250	<10	<15
% Sample>limit	**83.3**	0	0	0	**16.7**	**100**	**100**	0	0	0	**50**	**100**
SAWQ Irrigation	NG	6.5-8.4	<400	NG	NG	<1	<1	NG	NG	<100	<30	NG
% Sample>limit		0	**33.3**			**100**	**100**			0	0	
SAWQ Industrial	NG	6.0-8.0	<700	NG	NG	NG	NG	<300	<250	<100	NG	NG
% Sample>limit		**16.7**						0	0	0		

Note: % Sample > limit *(Guideline value) is the percentage number of samples not meeting maximum allowable value as specified by the relevant guideline or standard.* ***NG -*** *means no guideline value,* ***Values in bold*** *are the percentage exceedances of samples per guideline*

CHAPTER SIX: CONCLUSION AND RECOMMENDATION

6.1. Conclusion

The study came up with the following conclusions:

1. There was significant spatial and temporal variation ($p < 0.05$) of the physicochemical and microbial (except Total Coliforms) water quality parameters between January 2016 and March 2016. The pollution loads in the river followed the river flow rate trend and were in the range 0.2 tons/day – 256.4 tons/day for the biological oxygen demand, chloride, nitrates and total dissolved solids assessed for load estimation during the study period.

2. Principal Component Analysis (PCA) produced 3 principal components and all of them showed significant loading of EC, E.coli, TC and colour. The Cluster Analysis identified four optimal sampling points within the study area.

3. The overall Lower Great Usuthu River water quality status by means of DWQI was in category 3 indicating the water quality was marginally suitable. In terms of suitability, overall the Lower Great Usuthu River water was not suitable for domestic and irrigation water supply for crops to be consumed raw according to local water quality guidelines but suitable for category 3 industrial water supply uses. The river water quality was not suitable for domestic, category 3 industrial water supply uses and irrigation water supply for Nitrate sensitive crops according to international water quality guidelines.

6.2. Recommendations

The following recommendations were made from the study:

1. From the CA results, the study recommends the Department of Water Affairs

(Swaziland), to increase the monitoring stations for observing the Great Usuthu River water quality preferable at Mndobandoba (Sampling site 4) and Madlenya (Sampling Site 3). This can help improve water quality observing as the two current water quality observing stations located at Siphofaneni (Sampling Site 2) and Big Bend (Sampling site 6) respectively are inadequate.

2. From the Principal component analysis results, the study recommends that the principal water quality parameters (EC, TC, E.coli and Colour) be monitored regularly as they contribute significantly to variability of river water quality.
3. The study recommends proper treatment of the river water prior to domestic water use and more training be conducted to rural communities using the river water without treatment for domestic uses. For irrigation of crops to be consumed raw, treatment of river water by allowing it to settle for 48 hrs to reduce pathogens in the water is recommended.
4. River basin institutions, water utility companies and environmental management agencies should monitor pollution load regularly and there is a need for Swaziland to develop her own pollution load standards / guidelines for surface water.
5. Considering that the study was done during the off crop season for sugarcane processing, further studies should be done to weigh the river water quality situation during periods where industrial activities are at peak.

REFERENCES

Abbasi, T. and Abbasi, S., 2012. Why Water-Quality Indices, Water Quality Indices, Available at http://: www.kizi10game.org/water-quality-indices.pdf. Date assessed 12/11/2015:

Abowei, J.F.N., Davies, O.A. and Eli, A. 2010. Physico-chemistry, Morphology and Abundance of fin fish of Nkoro River, Niger Delta, Nigeria. International Journal of Pharmaceutical and Bio-physiology, 6 (2),144.

AccuWeather, 2016. Swaziland Weather. Available at http://www.accuweather.com/en/sz. Date assessed 20/05/2016.

Afifi, S, Alnahhal, S. and Abdelall, S., 2015. Developing an Integrated Sustainable Sanitation System for Urban Areas: Gaza Strip Case study. Procedia *CIRP*, 26, 767–774.

American Public Health Association (APHA). 2005. Standard Methods for the Examination of Water and Wastewater. 17th edition. American Public Health Association, Washington DC, USA.

Ariza, E., R. Sardá, J.A. Jiménez, J. Mora, Ávila. Y C., 2007. Beyond Performance Assessment Measurements for Beach Management: Application to Spanish Mediterranean Beaches. Coastal Management, 36(1), 47-66.

Ayaz, S.Ç., Aktaş, O., Dağlı, S., Aydöner, C., Atasoy Aytış, E., Akça. L, 2013. Pollution loads and surface water quality in the Kızılırmak Basin , Turkey. Desalination and Water Treatment ISSN: 1944-3994, 3994(July), 51(7-9), 1533-1542, Available at http://dx.doi.org/10.1080/19443994.2012.698814, Date assessed 07/07/2016.

Benvenuti, T, Kieling-Rubio, MA, Klauck, CR. and Rodrigues, MAS,O., 2015. Evaluation of water quality at the source of streams of the Sinos River Basin , southern Brazil. , 75(2), Available at http://dx.doi.org/10.1590/1519-6984.1513, Date accessed 03/07/2016.

Baldwin D. S., Wilson J., Gigney H. and Boulding A., 2009, Influence Of Extreme Drawdown on Water Quality Downstream of a Large Water Storage Reservoir, River Research and Applications, DOI: 10.1002/rra.

Basu, S. & Lokesh, K.S., 2013. Spatial and temporal variations of river water quality : A case study of River Kabini at Nanjangud in Karnataka. , 5(10), 591–596.

Calles O., Nyberg G. L. and Greenberg G. L., 2007, Temporal and Spatial Variation in Quality of Hypothetic water in One Unregulated and Two Regulated Boreal Rivers. Research and Applications, 23,829–842.

Chang, H. 2008. Spatial analysis of water quality trends in the Han River basin, South Korea. Water Research, 42**,** 3285-3304.

Charkhabi, A.H. & Sakizadeh, M., 2006. Assessment of Spatial Variation of Water Quality Parameters in the Most Polluted Branch of the Anzali Wetland , Northern Iran, 15(3), 395–403.

Chauban, A. Singh, S., 2004. Evaluation Of Ganga Water For Drinking Purpose. By Water Quality Index at Rishikesh, Uttarakhand, India

CPH Water, 2002. Water Quality Issues in the Usutu- Mhlathuze : Review of Water Quality

Status and Issues in the Mhlathuzane Water Management Area, (August), Department of Water Affairs and Forestry, South Africa.

Danielson, T., 2013. Avon Lake Municipalities Water Quality Report, Avon Lake, Ohio, Available at http://avonlakewater.org/wp-content/uploads/Avon-Lake-Water-Quality-Report-2013.pdf, Date Accessed 09/06/2016.

Department of Water Affairs and Forestry (DWAF) 1996a. South African Water Quality Guidelines for Agricultural Use : Irrigation, Volume 4, ISBN 0-7988-5338-7 (Set)ISBN 0-7988-5342-5 (Volume) Second Edition, Department of Water Affairs and Forestry, Pretoria, Republic of South Africa,

Department of Water Affairs and Forestry (DWAF), 1996b. South African Water Quality Guidelines for Industrial Use, Volume 3, ISBN 0-7988-5338-7 (Set) ISBN 0-7988-5341-7 (Volume) Second Edition, Department of Water Affairs and Forestry, Pretoria, Republic of South Africa,

Ding, J. Jiang, Y., Fu, L.,Liu, Q., Peng, Q., Kang, M., 2015. Impacts of Land Use on Surface Water Quality in a Subtropical River Basin: A Case Study of the Dongjiang River Basin, Southeastern China. *Water*, 7(8), 4427–4445.

Dlala, B, 2009. The Impact of Sub-Catchment Activity on River Water Quality: A Case Study of Mbabane River in the eZulwini Valley, Swaziland, Unpublished M.Sc. Thesis IWRM, University Of Zimbabwe, Faculty of Engineering, Department of Civil Engineering, Harare, Zimbabwe.

Dlamini, E., Hoko, Z., 2004. The Impacts of effluent from the Sappi Usuthu Pulp Mill on Water Quality of the Great Usuthu River.Water and Environmental Management Series, Water and Wastewater Management for Developing Countries (WAMDEC2004), .293 - 302.

Dlamini, N.S, Sithole, S.S, Ndlovu, J., 2014. The CDAA Framework for Development of Sustainable Large-scale Smallholder Irrigation Schemes in Swaziland. *Agriculture and Agricultural Science Procedia*, 2, 386–393. Available at: http://linkinghub.elsevier.com/retrieve/pii/S2210784314000552, Date Accessed 27/08/2015.

Elshorbagy, A. and Ormsbee, L., 2006. Object-oriented modeling approach to surface water quality management. *Environmental Modelling and Software*, 21(5), 689–698.

Environmental Protection Agency, 2001, Parameters of Water Quality, Intepretation and Standards, Published by the Environmental Protection Agency, Ireland .

Environmental Protection Agency (EPA), (2009) Pollution Load Protocol, Department of Environment and Climate Change NSW 59 Goulburn Street, Sydney.

Fadiran A.O., Mamba S.M. 2005. ‘Analysis of nitrates and nitrites in some water and factory effluent. Bull. Chem. Soc. Ethiopia, 19 (1),35- 44.

Fataei, E., 2011. Assessment of Surface Water Quality Using Principle Component Analysis and Factor Analysis. World Journal of Fish and Marine Sciences 3 (2): ISSN 2078-4589, IDOSI Publications, 2011, 3(2),159–166.

Fernandez N., Ramirez A., Solano F., 2004. Physico-chemical water quality indices– a comparative review. Bistua, Revista de la Facultad de Ciencias Basicas, 2(1): 19- 30..

Finotti, A.R., Susin, N., Finkler, R., Silva, M.D. and Schneider, V.E., 2014. Development of a monitoring network of water resources in urban areas as a support for municipal environmental management. WIT Transactions on Ecology and the Environment, 182, 133-143.

Gajbhiye, S., Sharma, S.K. and Awasthi, M.K., 2015. Application of Principal Components Analysis for Interpretation and Grouping of Water Quality Parameters. International Journal of Hybrid Information Technology, 8 (4) , 89-96. Available at http://dx.doi.org/10.14257/ijhit.2015.8.4.11, 8(4), pp.89–96, Date assessed 27/05/2016.

Global Water Partnership (GWP), 2000. Integrated Water Resources Management, No. 4, Stockholm, Sweden.

Government of Swaziland, 2009. Swaziland Agro Meteorological Update Report, Issue 10, season 2008/09, Swaziland Meteorological Department. Mbabane, Swaziland.

Government of Swaziland (GOS). 2005. Swaziland Household Income and Expenditure Survey (SHIES) 2000/01. Mbabane, Central Statistical Office, Ministry of Economic Planning and Development.

Islam, M.R.,Mamun, M.,Muyen, Z., Islam, M.R., Alum, Md. J.B., 2007. Water quality parameters along rivers. Department of Civil and Environmental Engineering, Shahjalal Universityof Science and Technology, Sy, Bangladash, 4(1), 159–167.

Kannel, P.R., Lee, S., Lee, Y.S., 2008. Assessment of spatial–temporal patterns of surface and ground water qualities and factors influencing management strategy of groundwater system in an urban river corridor of Nepal. J. Environ. Manage. 86, 595–604..

Kgabi N. 2015, Environmental Water Quality Processes Lecture Notes: Unit 1,Water Quality, Polytechnic of Namibia, School of Engineering, Department of Civil and Environonmental Engineering, Windhoek, Namibia.

Khanna, D.R., Bhutiani, R., Tyagi. B, Tyagi, P.K., Ruhela, M., 2013. Determination of water quality index for the evaluation of surface water quality for drinking purpose, International Journal of Science and Engineering. ISSN-2347-2200, 1(1),9 - 14. Available at Http;//www.ijse.org, Date assessed 19/05/2016.

Kirby-Smith, W.W. and N. White 2006. “Bacterial contamination associated with estuarine shoreline development.” Journal of Applied Microbiology. 100,648-657.

Kumar, R.N., Solanki, R. and Kumar, N.J.I. (2011) An assessment of seasonal variation and water quality Index of Sabarmati river and Kharicut canal at Ahmedabad, Gujarat. *Electronic Journal of Environmental, Agricultural and Food Chemistry*, *5*,2248-2261

Kuyeli, S., Masamba, W., Fabiano, E., Sajidu, S. and Henry, E. (2009) Temporal and Spatial Physical-chemical Water Quality in Blantyre Urban Streams. *Malawi Journal of Science and Technology*, 9 (1), 5-10.

Ligtvoet, W., Hilderink, H., Bouwman, A., Puijenbroek, P., Lucas, P. and Witmer, M., 2014. Towards a world of cities in 2050. An outlook on water-related challenges. Background report to the UN-Habitat Global Report. PBL Netherlands Envrionmental Assessment Agency. Available athttp://www.pbl.nl/sites/default/files/cms/publicaties/PBL_2014_Towards%20a%20world%20of%20cities%20in%202050_1325_0.pdf> (Date assessed 16/10/2015).

Matondo, J.I., 1997. Water Resource Development in the Usuthu Catchment Swaziland Under Climate Change. Part 2,1–9. University of Swaziland, Kwaluzeni, Swaziland. Available http://www.waternetonline.ihe.nl/waternetold/docs/Papers2003/WarfsaWaterNet%20Theme%203/EVALUATION%20OF%20THE%20IMPACT%20OF%20CLIMATE%20CHANGE%20ON%20HYDROLOGY%20AND%20.pdf. Date assessed 23/05/2016.

Mallin, M.A., Willams, K.E, Esham, E.C and Lowe, R.P., 2000. Effect of Human Development on Bacteriological Water Quality in Coastal Watersheds. Ecological Applications. 10(4),1047-1056.

Manyatsi, A.M., Brown, R., 2009, IWRM Survey And Status Report for Swaziland, Global Water Partnership Southern Africa,, Available at http://www.gwp.org/Global/GWP-SAf%20Files/IWRM%20Report_Swaziland.pdf, Date assessed 2/12/2015..

Manyatsi, A.M, and Tfwala, S.S, 2012, The Status of Domestic Water at Velezizweni, Swaziland, Department of Agricultural and Biosystems, Engineering, University of Swaziland, Current Research Journal of Social Sciences 4(2), 128-134.

Martins, P.O.undated, Water Quality Assessment And Pollution Control, WMA 509,Department of Water Resource Managemet and Agrometeriorology, UNAAB Abeokuta Ogun State, Nigeria.

Meals, D.W., Richards, R.P. & Tech, T., 2013. Pollutant Load Estimation for Water Quality Monitoring Projects, 1–21.

Mhlanga, B.N., Ndlovu L.S., Senzanje A., 2006. Impacts of irrigation return flows on the quality of the receiving waters: A case of sugar cane irrigated fields at the Royal Swaziland Sugar Corporation (RSSC) in the Mbuluzi River Basin (Swaziland). Physics and Chemistry of the Earth 31(15-16), 804-813.

Mhlanga, N.K., Matondo, J.I., Nobert, J., Salam, A., 2012. Evaluation of the impact of climate change on the inflow to Lubovane reservoir in Usutu catchment, Swaziland.Journal of Sustainable Development in Africa. 14:4, 15205509.

Mnisi, L.N., 2010. Assessment of the State of the Water Quality of the Lusushwana River, Swaziland, using selected Water Quality Indices, Unpublished M.Sc. Thesis IWRM, University Of Zimbabwe, Fuculty of Engineering, Department of Civil Engineering, Harare, Zimbabwe.

Mishra, A., Mukherjee, A. and Tripathi, B. D. 2009. Seasonal and Temporal Variations in Physico chemical and Bacteriological Characteristics of River Ganga in Varanasi. Int. J. Environ. Res., 3(3),395-402.

Mouratidis, I., Dimopoulos, G., Astaras, T. and Savvidis, S. (2010) Sustainable Water Resources Management through Use of GIS technologies, *Global Nest Journal*,12 (2),140-151.

Mthimkhulu, S., Dallas H., Day J, Hoko Z., 2005. Biologial Assessment of the state of water quality in the Mbuluzi River, Swaziland. In Mathew K.and Nhaphi I. (eds) Water and waste water management for developing countries. Selected proceedings foor water and waste water management for developing countries conference, Zimbabwe, 163 - 173.

Mts, S.Q. Bu, H., Tan, X., 2010. Ecotoxicology and Environmental Safety Temporal and spatial variations of water quality in the Jinshui River of the. *Ecotoxicology and Environmental Safety*, 1–7. Available at: http://dx.doi.org/10.1016/j.ecoenv.2009.11.07, Date accessed 12/05/2016.

Mwangi, F. N. 2014. Land Use Practices And Their Impact On The Water Quality Of The Upper Kuils River (Western Cape Province, South Africa). Magister Scientiae, University of the Western Cape.

Obire, O., Ogan, A. and Okigbo, R. (2008) Impact of Fertilizer Plant Effluent on Water Quality, *International Journal of Environmental Science and Technology*, vol. 5 (1), pages 107-118

Ollis, D.J., Dallas, H.F., Esler, K.J., Boucher, C., 2006. Bio assessment of the ecological integrity of river ecosystem using macroinvertebrates: an overview with a focus on South Africa. African J. Aquatic Sci. 31 (2), 205–227.

Olorode, O.A., Bamigbola, E.A. & Ogba, O.M., 2015. Comparative Studies of some River Waters in Port Harcourt based on Their Physico-Chemical and Microbiological analysis , Niger Delta Region of Nigeria. *International Journal of Basic and Applied Science*, 3(3), 29–37.

Oyhakilome, G.I., Aiyesanmi, A.F., Akharaiyi, F.C., 2012. Water Quality Assessment of the Owena Multi-Purpose Dam, Ondo State, Southwestern Nigeria. Journal of Environmental Protection 2,14-25.

Rabee, A.M., Al-fatlawy, Y.F. & Abd, A.N., 2011. Using Pollution Load Index (PLI) and Geoaccumulation Index (I-Geo) for the Assessment of Heavy Metals Pollution in Tigris River Sediment in Baghdad Region. , 14(4),108–114.

Ramadhan, J., (2007) *Impacts of agricultural activities to the water quality of the Mindu dam*, MSc. Thesis, University of Dar es Salaam (UDSM), Dar es Salaam, Tanzania.

Richards, R.P., 2008, Estimation of Pollutants Loads In Rivers and Streams : A Guidence Document For NPS Programs. U.S. Environmental Protection Agency, Region VIII, Water Quality Laboratory, Heildelburg College, 310 East Market Street , Tiffin, 1–134.

Ross, N., 2010. World water quality facts and statistics. *Annual Water Review*, World Water Day 2010, Clean Water for a Healtyh World, Pacific Institute, Available at Http://pacinst.org/reports/water_quality/water_quality_facts_and_stats.pdf, Date assessed 16/11/2016.

Roy, P.K. Deeya, R. Somnath, P. Gourab, B, 2014. Qualitative and Quantitative Assessment of Pollutional Load in River Ganga in West Bengal Using Statistical Technique. World

Applied Sciences Journal, 29(5),634–640.

Pallant, J., 2013. SPSS Survival Manual, 5th Edition, Buckingham, Open University Press, Available at http://www.academia.dk/BiologiskAntropologi/Epidemiologi/PDF/SPSS_Survival_Manual_Ver12.pdf, Date accessed 10/04/2016.

Panchani, M.H., Pandya, P.M.J. & Engineering, L.D.C., 2013. Identification and Quantification of Non-Point Sources of pollution to Sabarmati River , Ahmedabad. , 75(2), pp.71–75.

Sadhana, C. and Raj, K., 2013. Water Quality and Pollution load of River Mandakini at Chitrakoot , India. , International Research Journal of Environmental Science, Vol 2(6), ISSN 2319–1414, pp.13–19, Available at Http;// www.isca.in. Date assessed 27/05/2016.

Sankar, R., Ramkumar,L., Rajkumar, M., Sun, J. and Ananthan G. (2009), Seasonal variations inphysico-chemical parameters and heavy metals in water and sediments of Uppanarestuary, Nagapattinam, India. Journal of Environmental Biology, 31 (5), 681-686.

Schindler, N., Tränckner, J. & Krebs, P., 2008. Assessment of river water quality criteria with integrated models and extreme value statistics. , 1–10.

Singh, K.P., Malik, A., Sinha, S., 2005. Water quality assessment and apportionment of pollution sources of Gomti river (India) using multivariate statistical techniques: a case study. Analytica Chimica Acta 538, 355-374.

Smith L., Samways M, Taylor P., 2006. 'Assessing riparian quality using two complementary sets of bio indicators.' Biodiversity Conservation Journal 16, 2695–2713.

Southern African Development Community (SADC), 2012. Southern African Development Community, Environmental Legislation Handbook.
Available at http://www.saiea.com/dbsa_handbook_update2012/pdf/chapter13.pdf. Date assessed 18/09/2015.

Sorlini, S. Palazzini, D., Sieliechi, J.M., Ngassoum,M.B., 2013. Assessment of Physical-Chemical Drinking Water Quality in the Logone Valley (Chad-Cameroon). Sustainability 2013, 5, 3060-3076; doi:10.3390/su5073060, ISSN 2071-1050 , 3060–3076.

Swaziland Environment Authority (SEA). 2008. Swaziland Environment Authority Annual Report. Mbabane, Swaziland.

Swaziland Water Servics Corporation (SWSC), 2014. Swaziland Water Services Corporation Annual report for 2014, Zulwini, Swaziland.

Swaziland Water Partnership(SWP), 2008. Towards Integrated Water Resources Management, Mbabane, Swaziland.

Texas Natural Resource Conservation Commission (TNRCC), 2003. Two Total Maximum Daily Loads for Total Dissolved Solids and Sulfate in E . V . Spence Reservoir. Colorado River Municipal Water District, Austin, Texas. Available at http://www.tnrcc.state.tx.us/water/quality/tmdl/, Date assessed 08/07/2016.

Tomasz K, Ewa C. M., Mkhatshwa, B.H and Bogusław. B, (2007), Statistical characterisation of water quality in Great Usuthu River (Swaziland), Journal of Environmental Science and

Health, Part A Toxic/Hazardous Substances and Environmental Engineering Publication details, including instructions for authors and subscription information Available:http://www.informaworld.com/smpp/title~content=t713597268Swaziland_JES&H.pdf, Date assessed 13/07/2015,

UNEP. 2007. Global Drinking Water Quality Index Development and Sensitivity analysis report. United Nations environment programme Global environment monitoring system/water programme.

United Nations Framework Convention on Climate Change (UNFCCC). 2004. Swaziland's First National Communication. http://www.ecs.co.sz/unfccc/chapter4_3.htm. Date accessed 31 December 2015.

UN-Water, 2009 World Water Day brochure, http://www.unwater.org/worldwaterday/downloads/wwd09brochureenLOW.pdf.

UN-Waters, 2009, World water development report 3, Case study volume: Facing the challenges,Case of Cameron, Sudan, Swaziland, Tunisia and Zambia, (1) 8-12, London, UK.

Wandiga, S.O. 2010, Water Quality Issues in African Rivers, University of Nairobi, Department of Chemistry, Nairobi, Kenya.

Available at http://www.who.int/entity/ipcs/publications/en/ref.pdf. Date assessed 20/05/2016

WHO/UNICEF/WSSCC, 2004. 10 Things You Need to Know About Sanitation, pp.1–4. Available at: http://www.unwater.org/downloads/media/sanitation/10Things.pdf. Date accessed 12/09/2015.

Wikipadia, 2015. Maputo River, From Wikipadia, the Free Encyclopedia,Available at https://en.wikipedia.org/wiki/Maputo_River, Date Assessed 13/09/2015.

Wikipedia, 2016. Demographics of Swaziland. From Wikipedia Free Encyclopedia.Available at https://en.wikipedia.org/wiki/Demographics_of_Swaziland#Population_2, Date accessed 23/05/2016..

Wongsupapa C., S. Weesakula, R.Clementea, 2009. A. Das Gupta, River basin water quality assessment and management: case study of Tha Chin River Basin, Thailand,Water International, 34(3), 345-361.

Yang, K., Pinker, R. T., Ma, T., Koike, M. M., Wonsick, S. J., Cox, Y., Zhang, Stackhouse P., 2008. Evaluation of satellite estimates of downward shortwave radiation over the Tibetan Plateau. Journal Of Geophysical Research, (113), D17204, doi:10.1029/2007JD009736.

Yusuff, R. and Sonibare, J. (2004) Characterization of Textile Industries Effluent in Kaduna, Nigeria and Pollution Implications, Global Nest: The International Journal,6 (3),212-221..

Zhang, Z. Tan. X, Li. S., Bu. H., 2010. Surface water quality and its control in a river with intensive human impacts--a case study of the Xiangjiang River, China. Journal of environmental management, 91(12), 2483–90.

Available at: http://www.sciencedirect.com/science/article/pii/S0301479710001970, Date accessed 24/11/2015.

Zheng, F., Huang, C. and Norton, L.D., 2008. Joint Maputo River Basin Water Resources Study –Mozambique, Swaziland and South, Surface Water Quality. Plancent LTD, Outspan House, Centurion, Republic of South Africa, pp.2174–2182. Available at: https://www.dwaf.gov.za/maputobasinatlas/Reports/English/Report%207%20%20Surface%20WQ%20Final%20-v2.pdf. Date assessed 22/05/2016.

APPENDICES

Appendix 1: Swaziland Water Quality Objectives for Surface Water

Physicochemical Parameters	Standard/ Objective
Dissolved Oxygen	> 4 mg/l
pH	6.5–8.5
Electrical Conductivity	<1800 µS/cm
Turbidity	>5 NTU
Total Hardness	<1000 mg/l (as $CaCO_3$)
Chemical Oxygen Demand	<10 mg/l
Biological Oxygen Demand	<5 mg/l
Anions	
Nitrates	<10 mg/l
Nitrite	0.2 – 3 mg/l
Ammonia	<0.6 mg/l
Fluoride	<1.0 mg/l
Cations	
Iron	<1.0 mg/l
Manganese	<0.5 mg/l
Mercury	<0.001 mg/l
Cadmium	<0.003 mg/l
Aluminum	<0.2 mg/l
Microbial Parameters	
Total Coliforms	<10 cfu/100ml
Feacal Coliforms	<10 cfu/100ml

Adopted from: SADC Environmental Legislation Hand Book (2012)

Appendix 2: Swaziland Effluent Discharge Standards

Parameters	Units	Standard/objective
Colour	mg/l PtCo	<20
Odour/Taste		Not detectable after dilution
pH	pH scale	5.5 – 9.5
Electrical Conductivity	mS/m	<250
Dissolved Oxygen	% Sat	>75
Temperature	^{0}C	<35
COD	mg/l	<75
BOD	mg/l	<10
TDS	mg/l	<500
TSS	mg/l	<25
Sodium	mg/l	<50
Soap, Greece and Oil	mg/l	<100
Remaining Chlorine	mg/l	<0.1
Free and Saline Ammonia	mg/l	<10
Arsenic	mg/l	<0.5
Boron	mg/l	<1
Total Chromium	mg/l	<0.5
Copper	mg/l	<1
Phenolic Compounds	mg/l	<0.1
Phosphates	mg/l	<2
Lead	mg/l	<0.1

Adopted from: SADC Environmental Legislation Hand Book (2012).

Appendix 3: Field and Laboratory equipment used during the study

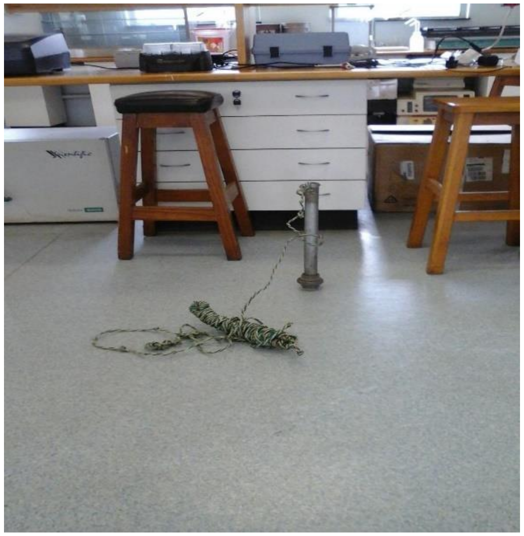


Figure 1: Surface Water Sampler (DWA)

Figure 2: Hach PC Multi Direct Multimeter

Figure 3: Hach Spectrophotometer

Appendix 4: Field Measurements

Figure 1: Garmini GPS 60 CSx

Figure 2: River flow data collection at GS19

Figure 3: Onsite water quality measurement

Appendix 5: Analysis of Variance for the Great Usuthu River Water Quality

Table 1: Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Temperature	0.223	6	0.200*	0.905	6	0.406
ph	0.144	6	0.200*	0.974	6	0.919
EC	0.213	6	0.200*	0.891	6	0.321
DO	0.200	6	0.200*	0.941	6	0.666
BOD	0.255	6	0.200*	0.847	6	0.148
COD	0.181	6	0.200*	0.967	6	0.871
E.coli	0.355	6	0.017	0.761	6	0.025
Total Coliforms	0.233	6	0.200*	0.953	6	0.766
Alkalinity	0.187	6	0.200*	0.903	6	0.394
Hardness	0.255	6	0.200*	0.885	6	0.293
Chlorides	0.189	6	0.200*	0.867	6	0.216
Nitrates	0.175	6	0.200*	0.980	6	0.952
Phosphates	0.157	6	0.200*	0.981	6	0.959
Colour	0.296	6	0.108	0.799	6	0.058

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table 2: Repeated measures Analysis of Variances (ANOVA)

Water Quality Parameters	**F**	**df1**	**df2**	**Significance (p value).**
Temperature	2.619	5	30	0.044
pH	2.582	5	30	0.047
EC	3.303	5	30	0.017
DO	2.805	5	30	0.034
BOD	2.650	5	30	0.042
COD	3.829	5	30	0.008
E.coli	3.999	5	30	0.007
TC	0.661	5	30	0.656
TA	5.525	5	30	0.001
TH	13.827	5	30	0.000
Chlorides	6.577	5	30	0.000
Nitrates	5.945	5	30	0.001
Phosphates	13.402	5	30	0.000
Colour	8.740	5	30	0.000

Appendix 6: Rainfall and river flow trend for Siphofaneni and Bigbend (January 2016 – March 2016)

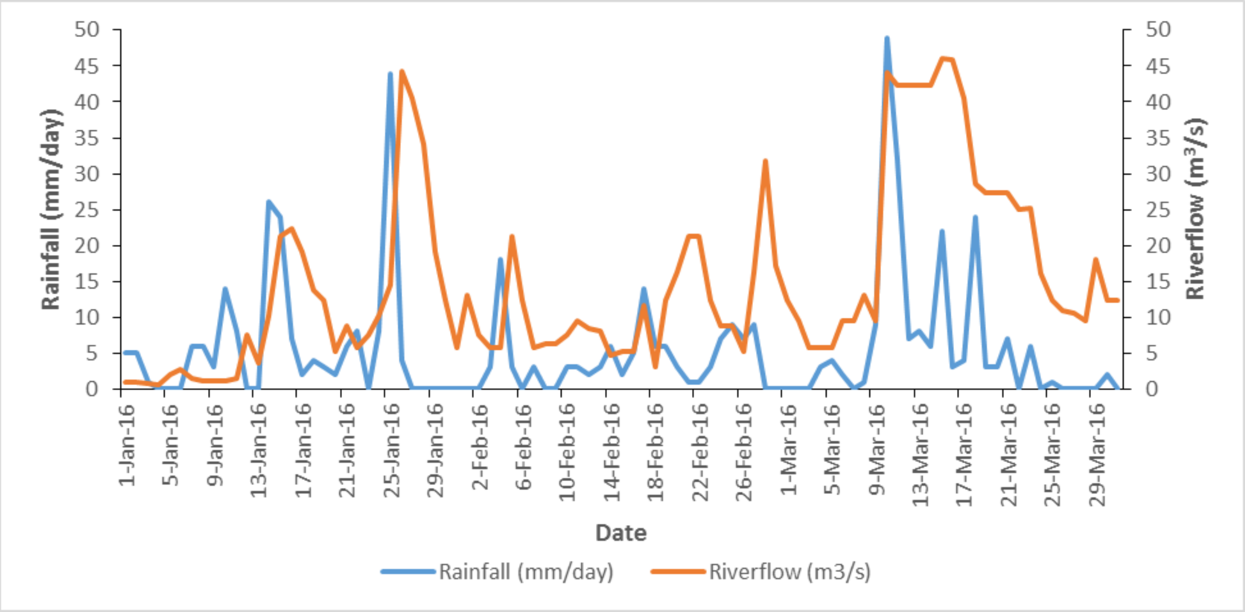


Figure 1: Siphofaneni (Site 2, Gauging station 6) rainfall and riverflow for period January – March 2016.

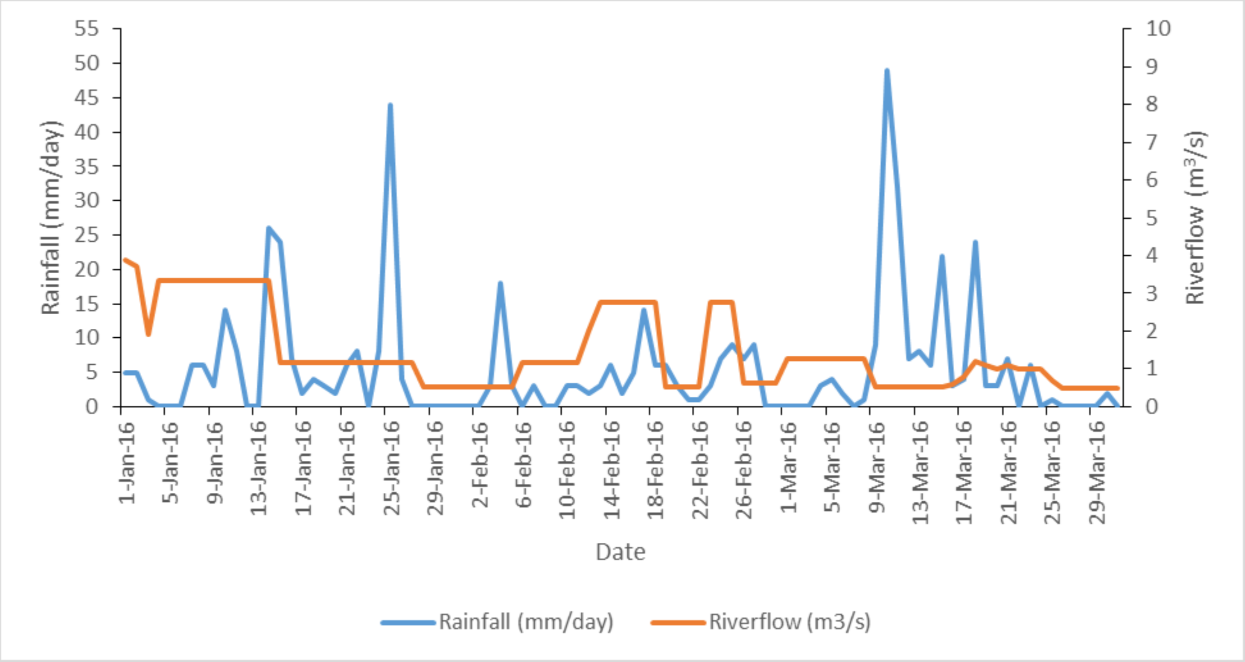


Figure 2: Siphofaneni (Site 3, Gauging station 19) rainfall and riverflow for period January – March 2016

Appendix 6: Continued

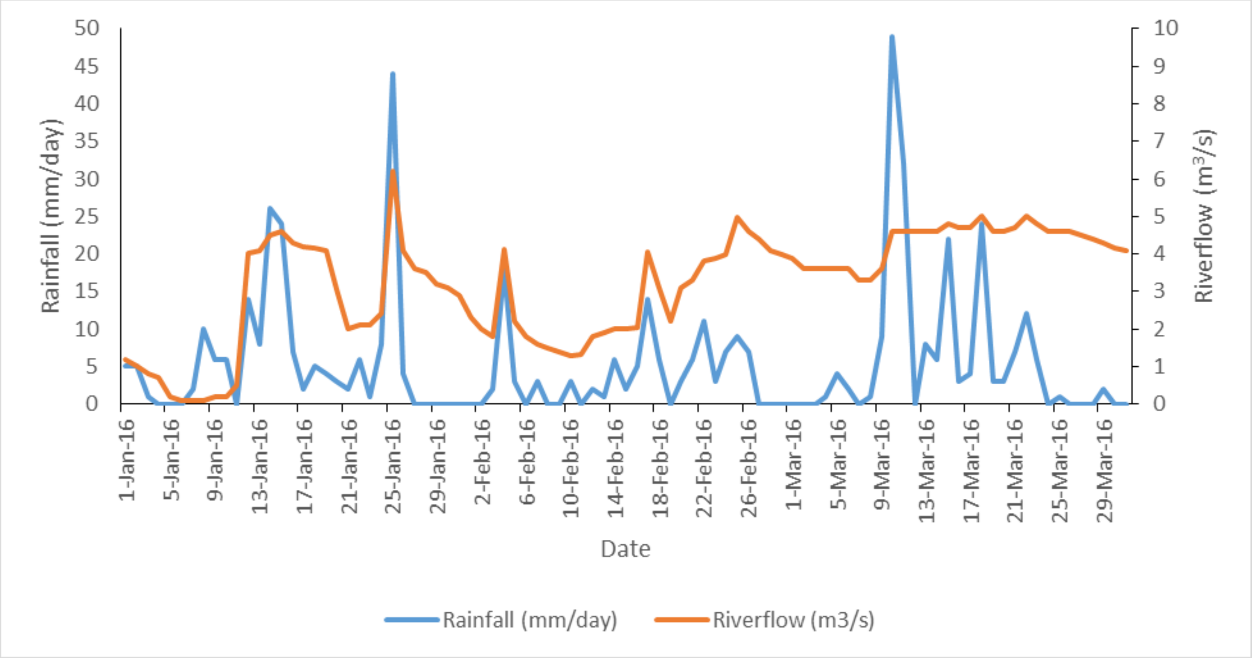


Figure 3: Bigbend (Site 6, Gauging station 16) rainfall and riverflow for period January – March 2016.

Appendix 7: DWQI results over the 6 sampling sites and 6 sampling sessions

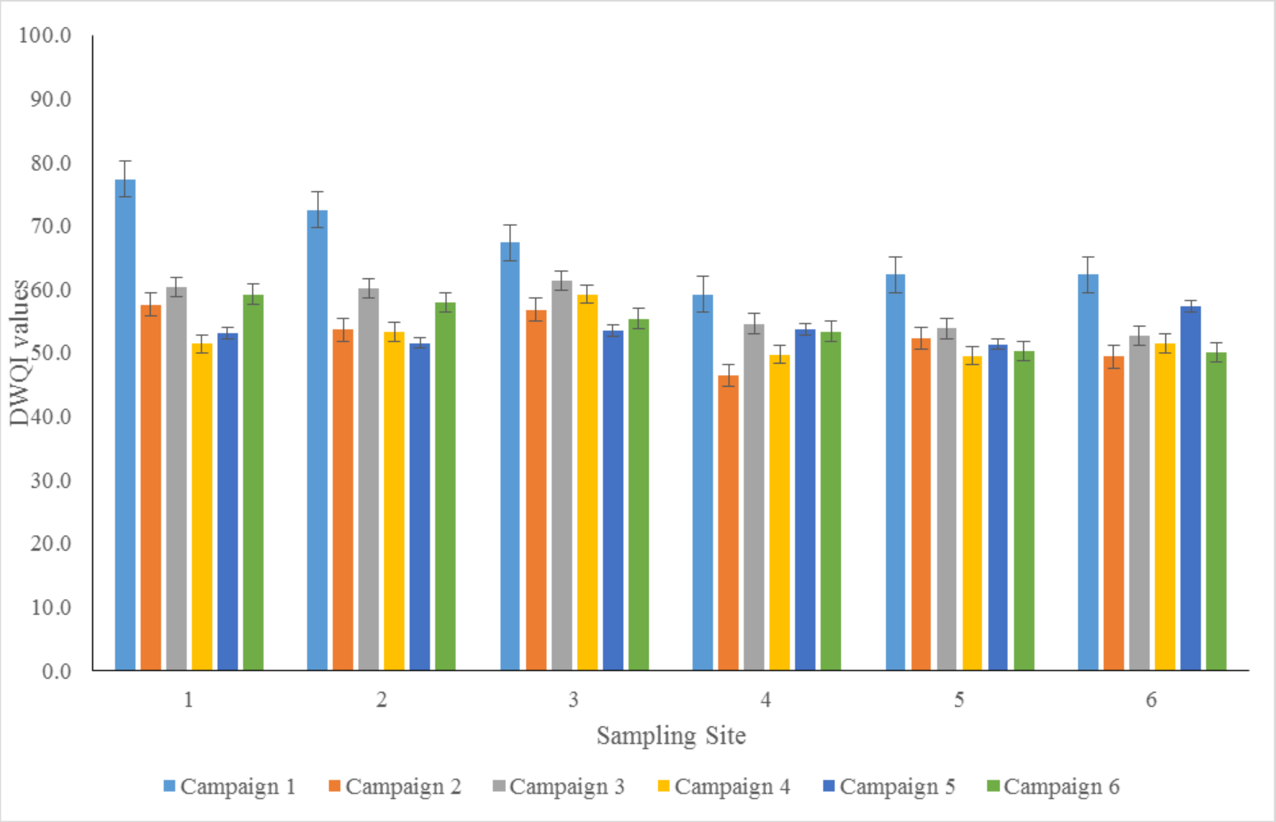
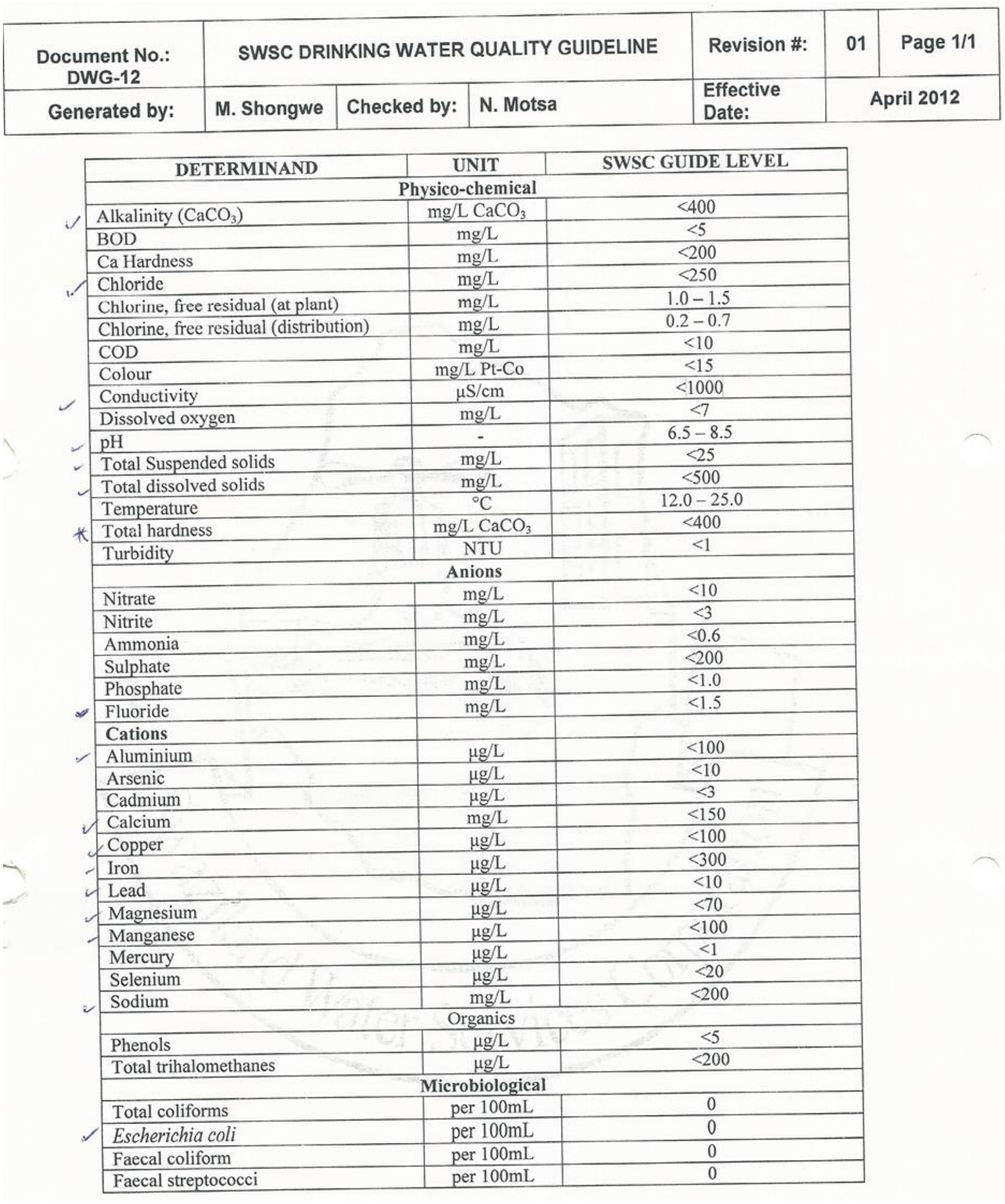


Figure 1. DWQI results for Great Usuthu River between January 2016 and March 2016

Appendix 8: Swaziland Water Services Corporation Drinking Water Quality Guidelines



Document No.: DWG-12	**SWSC DRINKING WATER QUALITY GUIDELINE**		**Revision #:**	**01**	**Page 1/1**
Generated by:	**M. Shongwe**	**Checked by:**	**N. Motsa**	**Effective Date:**	**April 2012**

DETERMINAND	**UNIT**	**SWSC GUIDE LEVEL**
	Physico-chemical	
✓ Alkalinity ($CaCO_3$)	mg/L $CaCO_3$	<400
BOD	mg/L	<5
Ca Hardness	mg/L	<200
✓ Chloride	mg/L	<250
Chlorine, free residual (at plant)	mg/L	1.0 – 1.5
Chlorine, free residual (distribution)	mg/L	0.2 – 0.7
COD	mg/L	<10
Colour	mg/L Pt-Co	<15
✓ Conductivity	µS/cm	<1000
Dissolved oxygen	mg/L	<7
✓ pH	-	6.5 – 8.5
✓ Total Suspended solids	mg/L	<25
✓ Total dissolved solids	mg/L	<500
Temperature	°C	12.0 – 25.0
* Total hardness	mg/L $CaCO_3$	<400
Turbidity	NTU	<1
	Anions	
Nitrate	mg/L	<10
Nitrite	mg/L	<3
Ammonia	mg/L	<0.6
Sulphate	mg/L	<200
Phosphate	mg/L	<1.0
✓ Fluoride	mg/L	<1.5
Cations		
✓ Aluminium	µg/L	<100
Arsenic	µg/L	<10
Cadmium	µg/L	<3
✓ Calcium	mg/L	<150
✓ Copper	µg/L	<100
✓ Iron	µg/L	<300
✓ Lead	µg/L	<10
✓ Magnesium	µg/L	<70
✓ Manganese	µg/L	<100
Mercury	µg/L	<1
Selenium	µg/L	<20
✓ Sodium	mg/L	<200
	Organics	
Phenols	µg/L	<5
Total trihalomethanes	µg/L	<200
	Microbiological	
Total coliforms	per 100mL	0
✓ *Escherichia coli*	per 100mL	0
Faecal coliform	per 100mL	0
Faecal streptococci	per 100mL	0

Appendix 9: South African Water Quality Guidelines

Table 1: SAWQ guidelines for irrigation

Parameter	Units	Guideline Value	Parameter	Units	Guideline Value
pH	pH Units	6.5 – 8.4	**Arsenic**	mgl^{-1}	< 2
Electrical Conductivity	µS/cm	< 400	**Chromium**	mgl^{-1}	< 1
Escherichia coli	MPN/100ml	< 1	**Cobalt**	mgl^{-1}	< 5
Total Coliforms	CFU/100ml	< 1	**Copper**	mgl^{-1}	< 5
Chlorides	mgl^{-1}	< 100	**Fluoride**	mgl^{-1}	< 15
Nitrates	mgl^{-1}	< 30	**Molybdenum**	mgl^{-1}	< 0.05
Aluminum	mgl^{-1}	< 5	**Nickel**	mgl^{-1}	< 2
Boron	mgl^{-1}	< 0.5	**Selenium**	mgl^{-1}	< 0.05
Beryllium	mgl^{-1}	< 0.5	**Sodium**	mgl^{-1}	< 70
Cadmium	mgl^{-1}	< 0.05	**Suspended Solids**	mgl^{-1}	< 50
Iron	mgl^{-1}	< 20			
Lead	mgl^{-1}	< 2	**Uranium**	mgl^{-1}	< 0.1
Lithium	mgl^{-1}	< 2.5	**Vanadium**	mgl^{-1}	<1
Manganese	mgl^{-1}	< 10	**Zinc**	mgl^{-1}	< 5

Adopted from: (DWAF, 1996a)

Table 2: South African Category 3 Industrial Water Quality Guidelines

Parameter	Units	Guideline Value	Parameter	Units	Guideline Value
pH	pH units	6.5-8.0	**Manganese**	mgl^{-1}	< 0.2
Electrical Conductivity	μScm^{-1}	<700	**Silica**	mgl^{-1}	< 0.2
COD	mgl^{-1}	<30	**Sulphate**	mgl^{-1}	< 200
Alkalinity	mgl^{-1}	<300	**TSS**	mgl^{-1}	< 5
Hardness	mgl^{-1}	<250	**TDS**	mgl^{-1}	< 450
Chloride	mgl^{-1}	<100	**TH**	mgl^{-1}	< 250
Iron	mgl^{-1}	< 0.5			

Adopted from: (DWAF, 1996b)

Appendix 10: FAO Irrigation Water Quality Guidelines

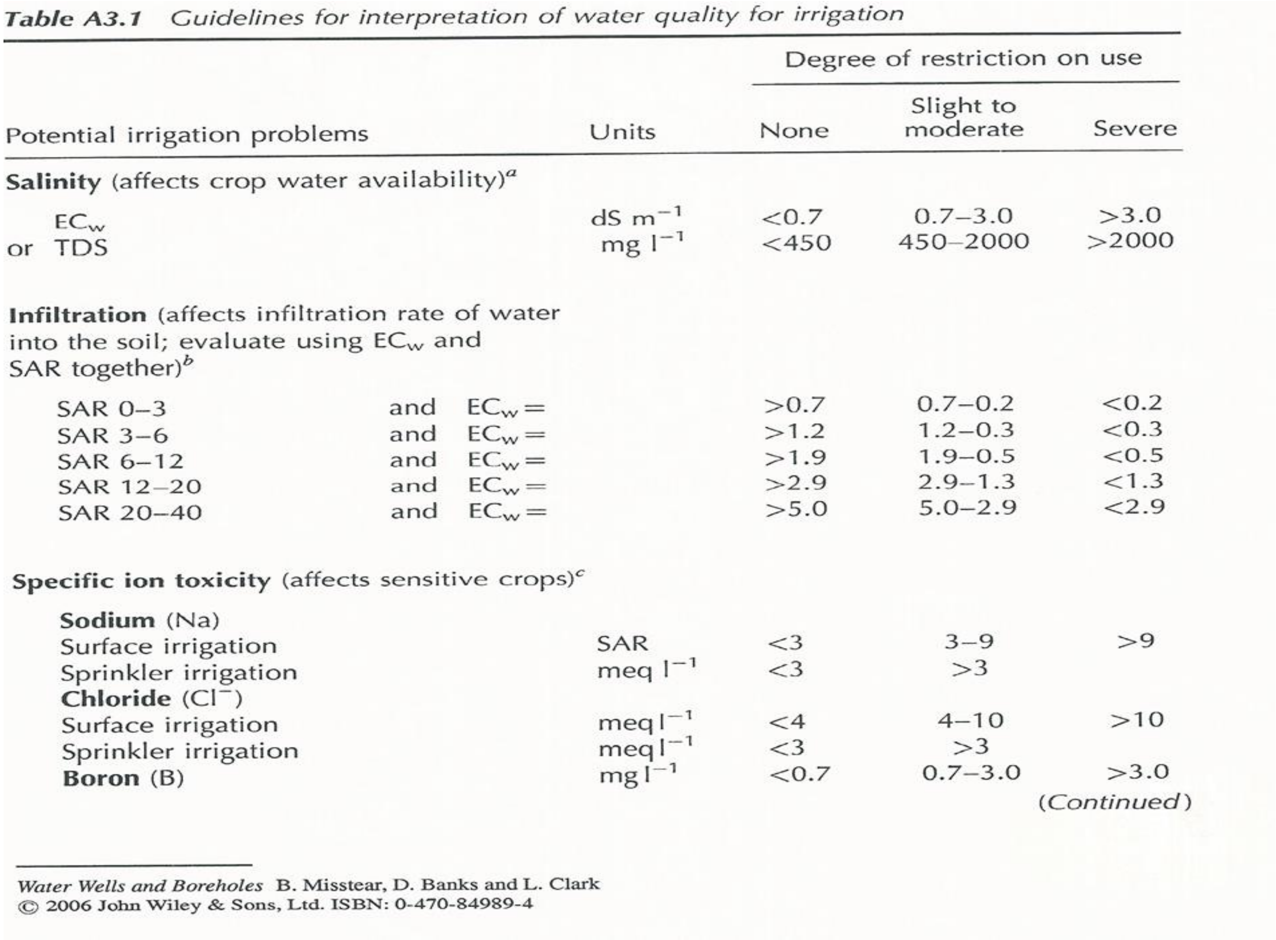


Table A3.1 *Guidelines for interpretation of water quality for irrigation*

		Degree of restriction on use		
Potential irrigation problems	Units	None	Slight to moderate	Severe
Salinity (affects crop water availability)[a]				
EC_w	dS m^{-1}	<0.7	0.7–3.0	>3.0
or TDS	mg l^{-1}	<450	450–2000	>2000
Infiltration (affects infiltration rate of water into the soil; evaluate using EC_w and SAR together)[b]				
SAR 0–3 and EC_w =		>0.7	0.7–0.2	<0.2
SAR 3–6 and EC_w =		>1.2	1.2–0.3	<0.3
SAR 6–12 and EC_w =		>1.9	1.9–0.5	<0.5
SAR 12–20 and EC_w =		>2.9	2.9–1.3	<1.3
SAR 20–40 and EC_w =		>5.0	5.0–2.9	<2.9
Specific ion toxicity (affects sensitive crops)[c]				
Sodium (Na)				
Surface irrigation	SAR	<3	3–9	>9
Sprinkler irrigation	meq l^{-1}	<3	>3	
Chloride (Cl^-)				
Surface irrigation	meq l^{-1}	<4	4–10	>10
Sprinkler irrigation	meq l^{-1}	<3	>3	
Boron (B)	mg l^{-1}	<0.7	0.7–3.0	>3.0

(*Continued*)

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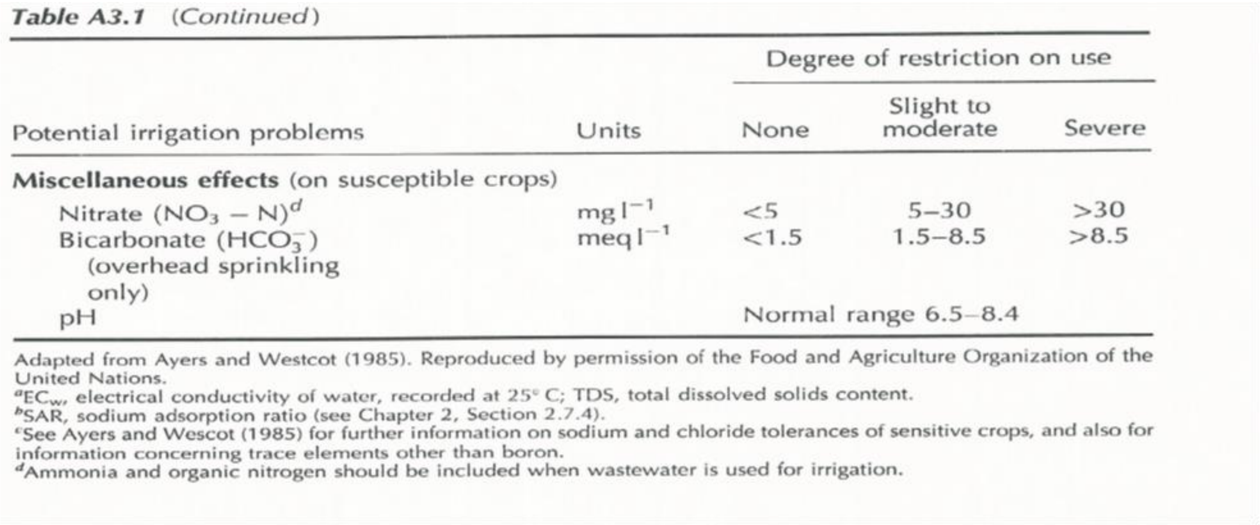

Table A3.1 (*Continued*)

		Degree of restriction on use		
Potential irrigation problems	Units	None	Slight to moderate	Severe
Miscellaneous effects (on susceptible crops)				
Nitrate ($NO_3 - N$)[d]	mg l^{-1}	<5	5–30	>30
Bicarbonate (HCO_3^-) (overhead sprinkling only)	meq l^{-1}	<1.5	1.5–8.5	>8.5
pH		Normal range 6.5–8.4		

Adapted from Ayers and Westcot (1985). Reproduced by permission of the Food and Agriculture Organization of the United Nations.

[a] EC_w, electrical conductivity of water, recorded at 25° C; TDS, total dissolved solids content.

[b] SAR, sodium adsorption ratio (see Chapter 2, Section 2.7.4).

[c] See Ayers and Wescot (1985) for further information on sodium and chloride tolerances of sensitive crops, and also for information concerning trace elements other than boron.

[d] Ammonia and organic nitrogen should be included when wastewater is used for irrigation.

Appendix 11: World Health Organization drinking water quality guidelines

Table 1: W.H.O. drinking water guidelines

PARAMETER	UNIT	LIMIT	PARAMETER	UNIT	LIMIT	PARAMETER	UNIT	LIMIT
Aluminium.	mgl^{-1}	0.2	Fluoride.	mgl^{-1}	1.5	Selenium.	mgl-1	0.01
Arsenic.	mgl^{-1}	0.05	Nitrates.	mgl^{-1}	10	Sodium.	mgl-1	200
Barium.	mgl^{-1}	0.05	Nitrites.	mgl^{-1}	-	Zinc.	mgl-1	5
Berylium.	ugl^{-1}	0.2	Sulphates.	mgl^{-1}	400	Chloride	mgl-1	250
Cadmium.	ugl^{-1}	5	Suphides.	mgl^{-1}	0	Cyanide.	mgl-1	0.1
Calcium.	mgl^{-1}	200	TOTAL "drins".	ugl^{-1}	0.03	Manganese.	mgl-1	0.1
Chromium.	mgl^{-1}	0.05	TOTAL "ddt".	ugl^{-1}	1	Mercury	ugl-1	1
Copper.	mgl^{-1}	1	Hydrocarbons.	mgl^{-1}	0.1	**Microbial Parameters**		
Iron Total.	mgl^{-1}	0.3	Anionic Detergents.	mgl^{-1}	0	Total Bacteria.	Counts/100ml	100
Lead.	mgl^{-1}	0.01	pH.	pH units	9.2	Total Coliform.	CFU/100ml	0
Magnesium.	mgl-1	150	Total Dissolved Solids (TDS).	mgl^{-1}	1500	Escherichia coli.	Counts/100ml	0
Total Alkalinity (TA).	mgl^{-1}	500	Total Hardness (TH).	mgl^{-1}	500	Salmonella.	Counts/100ml	0

Appendix 12: Comparison of GUR water quality results with WHO and FAO water quality guidelines

Table 1.0: Summary water quality analysis results and comparisons to international water quality guidelines

Sampling Sites	temp	pH	EC	DO	BOD	E.coli	TC	TA	TH	Chloride	Nitrates	Colour
Site 1	25.6	7.6	125.7	29.8	4.3	390	728	10.8	46.5	3.9	8.6	373.3
Site 2	26.5	7.7	132.1	30.2	5.0	308	939	10.3	52.2	3.9	9.8	372.3
Site 3	24.8	7.8	198.8	31.8	2.5	353	487	12.5	48.5	6.8	4.2	97.0
Site 4	28.4	8.0	319.3	30.5	3.3	647	1388	9.9	37.7	11.3	14.4	510.5
Site 5	29.4	8.0	670.7	30.6	2.0	431	1095	9.2	36.8	15.4	16.8	488.0
Site 6	29.0	8.2	478.6	32.7	2.7	424	1122	9.5	39.0	14.7	23.0	478.8
WHO	NG	<9.2	<250	NG	NG	0	0	<500	<500	<250	<10	NG
% Sample>limit		0	**50**			**100**	**100**	0	0	0	**50**	
FAO	NG	6.5-8.4	<700	NG	NG	NG	NG	NG	NG	<80	<5	NG
% Sample>limit		0	0								**83.3**	

Note: ***% Sample > limit*** *(guideline value) is the percentage number of samples not meeting maximum allowable value as prescribed by the relevant standards or guidelines* ***NG-*** *means no guideline value prescribed.* ***Values in bold*** *are the percentage exceedance per guideline*