THE PUBLIC HEALTH RISK OF PATHOGENIC BACTERIOLOGICAL CONTAMINATION OF WATER IN THE KAFUBU RIVER

Able Matola

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A research report submitted in partial fulfillment of the requirements for the award of the Master's Degree in Disaster Studies of Mulungushi University

August 2018

CERTIFICATION

The undersigned hereby certifies and recommends the research report to be accepted by Mulungushi University in partial fulfilment of the requirements for the award of the Degree of Master of Disaster Studies.

Name: ……………………………………….. **Signature: …………………………**

(Supervisor)

Date: …………..

STATEMENT OF DECLARATION AND COPYRIGHT

Declaration

I, Able Matola, do hereby declare to the Senate of Mulungushi University that this report is a true reflection of my own efforts with due and full acknowledgement of the ideas and works of others where required, and has never been submitted as such to any University. Therefore, I take full responsibility of the findings of this research and so commit myself in signing hereunder.

Signature: …………………………………….

Date: ………………………………………......

Copyright

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I am deeply grateful to the Almighty God for the love and care rendered to me and my family during the course of my studies at Mulungushi University (MU). I am further grateful to MU for the study opportunity given to me in the Master's degree programme in Disaster studies, and I am specially thankful to all the lecturers in the Department of Disaster Management Studies of the School of Agriculture and Natural Resources for the guidance given to me during my study period at the University. My special tribute of gratitude is particularly paid to my supervisor, Mr. J.T. Mwale, for the enduring support given to me to successfully complete my research work for the Master's. I also thank the Managing Director of the Kafubu Water and Sewerage Company, Mr. A. K Mwaba, and his team for the time and support given to me during the study period. I would also like to thank the Ethical Committee of the Tropical Disease Research Centre (TDRC), Ndola, Zambia for according me the opportunity to use their Microbiology laboratory. I am particularly grateful to the technical staff of the TDRC namely: Mr. M. Tembo, Mr. Derrick Banda and Mr. Ephraim Chikwanda and not forgetting the Head of Department Dr. Kasongo for their support to my research. I would also love to thank Mr. Malambo Obey, Mumba Kolala, Mr. Siamatendu Host, Simunza Angela, Mr. Mtonga John and Mr. Chalawila Tresford for the technical support rendered to me during the data collection and analysis phases of my research. Finally, I wish to acknowledge my course mates who played unique roles during the long journey, as we professionally, academically and mutually participated in making sense of the different obstacles faced and providing encouragement to one another in times when things looked impossible to achieve. Most importantly, I am gratified by the love from my beautiful wife, Bwalya Mwamba, who unconditionally supported me through and through during my years of study at MU.

DEDICATION

I dedicate this work to my late dad and mum, my wife, my little children, Bays and Beth, and my three brothers.

ABSTRACT

This research assessed the public health risk of bacteriological water contamination of the Kafubu River in Zambia against the backdrop of limited research on the ambient surface water quality of the river that is flowing in a catchment area characterised by high human activity. Human activity, particularly sewer effluent disposal, is continually loading the river with bacteria that could pose adverse health risks to the public. The study was based on a systematic sampling design by which geo-referenced sampling points were selected at 500 m intervals along the section of the river where the intensity of human activity was very high. Grab water samples were then collected in the months of October and November, 2017 and were analyzed for the bacteriological concentrations of total coliforms, faecal coliforms and *Escherichia coli* known to have a bearing on public health. Using exploratory data analysis to generate descriptive statistics, followed by single-factor analysis against the threshold for the ambient water quality of rivers, it was found that the bacteriological concentrations of total coliforms (2,497-17, 101cfu/100ml), faecal coliforms (925 - 13,083 cfu/100ml) and *Escherichia coli* (27 – 4,302 cfu/100ml) indicated that the ambient water quality of the Kafubu River was impaired. Geo-statistical modeling further showed that the bacteriological concentrations were spatially concentrated around the sewer effluent discharge points along the river. This water pollution scenario could then be attributed to ineffective wastewater treatment at the sewerage plants within the river catchment. The study concludes that there is a public health risk of water-borne disease in direct use of raw water from the Kafubu River on account of the significantly high bacteriological water contamination, and it is recommended as such that best management practices for sewer effluent disposal into the river should be enforced, and further research is required to model water pollution at varying time scales across the river continuum.

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LIST OF ABBREVIATIONS AND ACRONYMS

APHA	American Public Health Association
CFU	Colony Forming Unit(s)
E. Coli	Escherichia Coli
FC	Faecal Coliform
GPS	Global Positioning System
IWRM	Integrated Water Resources Management
KWSC	Kafubu Water and Sewerage Company
MDS	Masters in Disaster Studies
SANR	School of Agriculture and Natural Resources
SP	Sampling Point
TC	Total Coliform
TCBS	Thiosulfate citrate bile salts sucrose agar
TDRC	Tropical Diseases Research Centre
USEPA	United States Environmental Protection Agency
WARMA	Water Resources Management Authority
WHO	World Health Organization
XLD	Xylose Lysine Desoxycholate agar
ZEMA	Zambia Environmental Management Agency

CHAPTER ONE

1. INTRODUCTION

1.1 Background

The pathogenic contamination of water is a persistent threat to public health in many parts of the world, particularly in the underdeveloped countries where raw water is insufficiently treated for drinking purposes or is consumed directly without treatment. For example, most ccommunities in sub-Saharan Africa access and source their domestic water from unprotected water sources such as rivers, which are susceptible to contamination by faecal material (Chikumbusko *et. al*, 2013). The quality of water in a water body can be degraded by microbial contaminants from various sources within the catchment area of the water body. As such direct consumption of raw water from unprotected sources poses public health risks including water-borne disease outbreaks caused by pathogenic microbial contaminants. Microbial contamination of water can contribute to high morbidity and mortality rates from diarrheal diseases leading to epidemics. Therefore, sources of pollution of water need to be identified and managed to avert the potential public health risks.

Surface water bodies such as rivers and lakes are susceptible to point source and non-point source pollution from their catchment areas. Point source pollution results from any discernible, confined, and discrete conveyance such as a pipe, ditch, ship or factory smokestack. Examples of point sources of pollution include industrial and wastewater treatment plants effluent discharge points. Non-point source pollution results from many diffuse sources such as farmland, city streets, construction sites, suburban lawns and roofs. Knowledge of the potential sources of water pollution is important for planning and management of water quality monitoring programmes for protecting the wellbeing of both the public and environment.

The Kafubu River in Zambia drains an area characterised by diverse human activities including industry, mining, agriculture, fishing, recreation and municipal services. Most of these activities generate waste that is discharged into the river thereby potentially degrading the physical, chemical and biological quality of water. The growing intensity of human activity in the catchment area poses both public and ecological risks. This calls for risk mitigation measures to prevent the disastrous effects of water pollution in the river. Thus, water quality assessments are required to raise public health awareness and engender best management practices for pollution control. Njoyim *et. al.* (2016) stresses the importance of water quality assessments that they are critical to protect the wellbeing of the public by giving information to public health policy makers. Therefore, this research responds to the need for water quality assessments, and is focused on the bacteriological quality of water in the Kafubu River in view of the high intensity of human activity that is discharging effluents into the river, particularly from the wastewater treatment facilities.

1.2 Problem Statement

Continuous discharge of sewer effluents into the Kafubu River in Zambia, along with diffuse inflow of runoff water laden with faecal matter from the catchment area, may increase the level of pathogenic bacteriological contamination of water beyond the threshold for the ambient quality of water in the river. However, the possibility of pathogenic bacteriological contamination of water of the Kafubu River has not been assessed for the public health risk of water-borne disease in direct use and consumption of raw water by the community in the catchment area.

1.3 Research Objectives

Against the background of limited research into the bacteriological quality of the Kafubu river water, the general and specific objectives of the study are stated in Section 1.3.1 and 1.3.2 respectively.

1.3.1 General Objective

The research was aimed at assessing the public health risk of pathogenic bacteriological contamination of water in the Kafubu River in Zambia as part of water quality monitoring of the river for preventive disaster management of water-borne disease outbreaks.

1.3.2 Specific Objectives

The specific objectives of the research were threefold:

1) To estimate the bacteriological concentrations of total coliforms, faecal coliforms and *Escherichia coli* in the Kafubu River;
2) To evaluate the bacteriological concentrations of total coliforms, faecal coliforms and *Escherichia coli* against the threshold for the ambient state of water quality in the Kafubu River; and
3) To determine the spatial distribution of total coliforms, faecal coliforms and *Escherichia coli* in the Kafubu River.

1.4 Research Questions

1) What are the bacteriological concentrations of total coliforms, faecal coliforms and *Escherichia coli* in the Kafubu River?
2) How do the bacteriological concentrations of total coliforms, faecal coliforms and *Escherichia coli* compare against the threshold for the ambient state of water quality in the Kafubu River statistically significant?
3) What is the spatial distribution of total coliforms, faecal coliforms and *Escherichia coli* in the Kafubu River?

1.5 Significance of the Study

Kafubu River is of great importance to its communities along its banks and the rest of the city, therefore the quality of its water is worth assessed. The study assessed the bacteriological level of contamination in the river and hoped that the findings of the study will be helpful in policy making process in public health and environmental management institutions in the country. The study will be also used as the baseline study in future by other research studies on the same field. Studies of this kind can be replicated to other rivers in the country and finally this study will add value to the existing body of knowledge.

1.6 Limitations of the Study

The study was successfully conducted although it had some challenges. There was a challenge in accessing the river during sampling point identification due to excessive grass. However, the researcher managed to access the river by making routes through slashing. Logistics was another challenge faced by the researcher during water sample collection process. Nonetheless, the researcher managed to arrange for the transport and samples were collected in good time.

1.7 Conceptual and Theoretical Framework

1.7.1 Conceptual Framework

It is well known that man depends on ecosystems services; therefore, it is important to identify, assess, and undertake practical actions that can enhance human well-being without undermining ecosystems (Alcamo *et al*, 2003). Humans influence and are influenced by ecosystems through multiple interacting pathways as illustrated in (**Figure. 1**) (Alcamo *et al*, 2003). Bacteriological water quality of the river as ecosystem can be too affected by human through direct or indirect contaminants discharged into the river. It could be point source or nonpoint source contamination. For example effluent discharge is the main source of microbial contamination in the rivers world over and this could be a point source of contamination from a particular sewage treatment plant discharging into the river which is a surface water source.

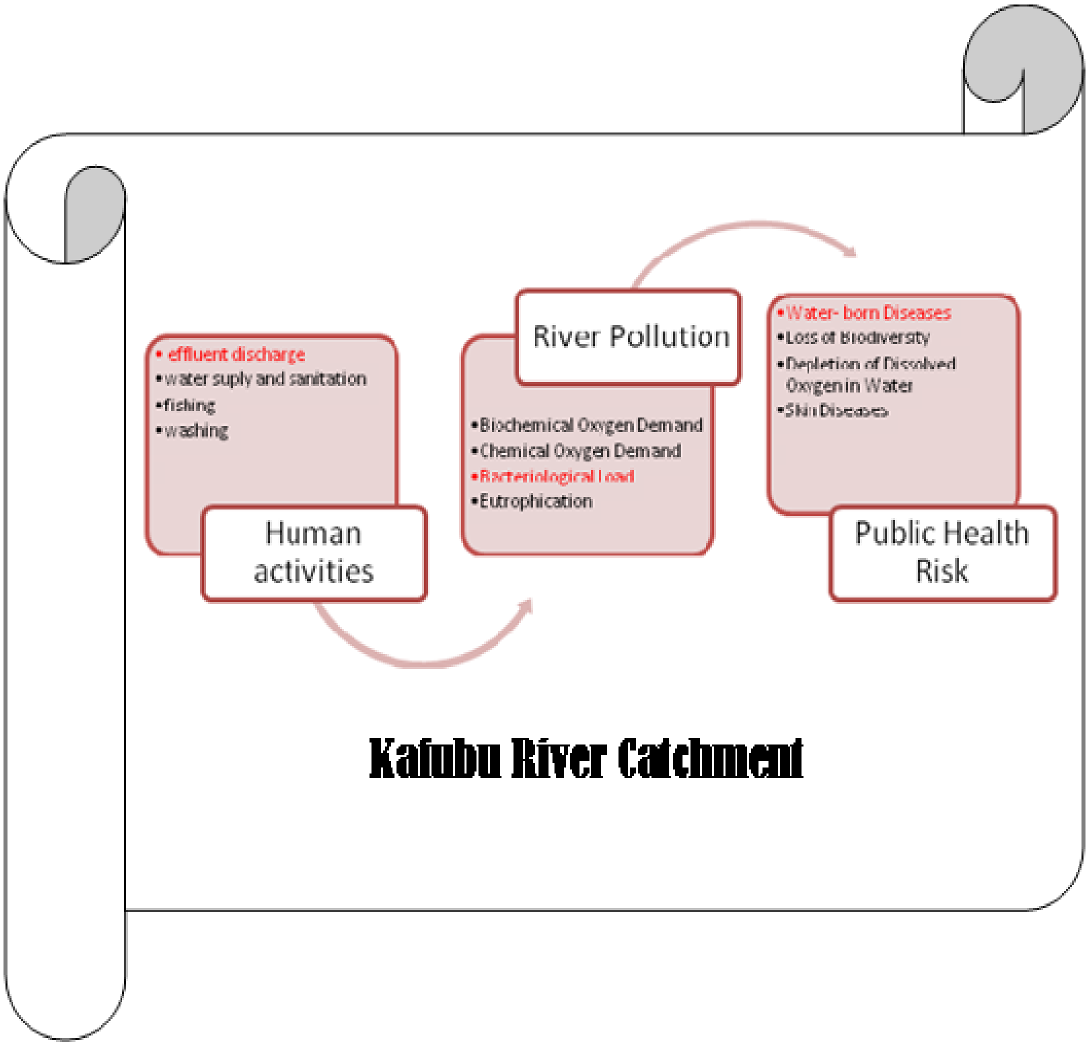

Figure 1: Conceptual framework for assessing the public health risk of bacteriological contamination of the Kafubu River, Zambia

Human activities can lead to an increase in microbial contaminants in the river which can lead to river water contamination and hence threaten the public health as shown in (**Figure. 1**), because surface water can work as a transmitter of diseases and so human health may be compromised as a result of contaminated water used as a source of domestic, agricultural, industrial, fishing and recreational water (Oliver *et al*, 2005).Therefore, an assessment of water quality of such a river system can of great importance to acertain its quality.

1.7.1.2 Theoretical Framework

This study was set forth on the Ecosystems and Human Well-being framework, a Framework for Assessment. This framework tries to link the ecosystem services, human activities and the consequences of human activities on the ecosystem as illustrated in **Figure 1**. As we may know, ecosystems provide us with critical services for our survival, services such as provisioning, regulating, cultural, and supporting services. If one of the above ecosystems' services is compromised by exceeding its carrying capacity, the environment will be unable to function well and the end result(s) will be disease, shortage of resources and so on. For example if the regulating service is compromised by exceeding its carrying through discharge of contaminants, this will lead to ecosystem inefficiency in purification process and hence lead to human ill-being. Human well-being and progress toward sustainable development are vitally dependent upon Earth's ecosystems (Alcamo *et al*, 2003). The ways in which ecosystems are affected by human activities will have consequences for the supply of ecosystem services including food, fresh water, fuel wood, and fibber and for the prevalence of diseases, the frequency and magnitude of floods and droughts, and local as well as global climate (Alcamo *et al*, 2003).

Alcamo *et al*, (2003) stated that Human well-being and progress toward sustainable development are vitally dependent upon improving the management of Earth's ecosystems to ensure their conservation and sustainable use. But while demands for ecosystem services such as food and clean water are growing, human actions are at the same time diminishing the capability of many ecosystems to meet these demands. Human demands for ecosystem services are growing rapidly. At the same time, humans are altering the capability of ecosystems to continue to provide many of these services. Changes in availability of all these ecosystem services can profoundly affect aspects of human well-being ranging from the rate of economic growth and health and livelihood security to the prevalence and persistence of poverty (Alcamo *et al*, 2003). Berkes and Folke (1998) stated that humans are not seen as separate from their environment, but rather actively impacting upon and being influenced by it.

This means that management of this relationship is required to enhance the contribution of ecosystems to human well-being without affecting their long-term capacity to provide services. Therefore, conducting environmental assessments such as bacteriological water quality assessment of the riverwill not only enhance the ecosystem management but also improving human well-being.

CHAPTER TWO

2. LITERATURE REVIEW

This chapter reviews and presents various literatures exhibited by other different researchers in relation to bacteriological water quality assessment for surface water bodies.

2.1 Bacteriological water quality assessment for surface water bodies

Surface water bacteriological contamination is a source of worry worldwide nowadays (Mahananda *et al* 2005). The contamination has been accelerated due to rapid urbanization and industrialization. The large scale urban growth due to increase in population has increased domestic effluents while industrial development has resulted in a generation of copious volume of industrial effluents (Pramod and Arvind, 2014) all these can enter into the river through point or non point sources. Prior Surface water bacteriological quality assessment studies have shown an increase in bacteriological contamination in most of the rivers been assessed world over (Emőke *et al*, 2013)

2.2 Global Surface Water bacteriological Quality Situation

Bacteriological level of contamination in surface water has been increased even at global level in most of the key rivers. The research works have indicated this increase in bacteriological contamination. For example Emőke et al, (2013) conducted bacteriological water quality assessment on Danube River one of the key rivers in Europeit was discovered that the river had high levels of bacteriological load. Similar assessments were conducted on rivers Arges, Siret and Prut and they were also significantly polluted (Emőke et al, 2013).

In India, Bacterial pollution in river Gomati was seen to increase day by day due to discharge of organic wastes, human excreta, sewage waste, municipal garbage and toxic discharge from factories (Pramod and Arvind, 2014). At Jaunpur, the river is being polluted by a number of small and large drains, carrying municipal sewage of adjoining areas.

The present investigation reveals the bacteriological characteristics and their monthly variation in the river water during the year 2009 and 2010 (Pramod and Arvind, 2014). Another study was conducted on River Tungabhadra in India and pathogenic bacteria were observed. This was because the river was contaminated by sewage effluents (Basavaraj *et al*, 2014)

2.3 Africa Surface Water bacteriological Quality Situation

Surface water bacteriological contamination is now common everywhere and African is not spared. The contamination is mostly coming from improper land use, indiscriminate waste disposal and other domestic uses (Ayivor1 and Gordon, 2012).

Research works have shown the bacteriological water contamination in most of the studied rivers in Africa. Clear evidence has been seen in Asa River Ilorin, Nigeria where Olatunji *et al* (2011) conducted water quality assessment and it was observed that the river is contaminated with high levels of bacteria. In Enugu area, South-Eastern, Nigeria research on surface water on all the rivers in this area were all positive with high levels of feacal coliforms and Escherichia coli a sign of feacal matter contamination (Aniebone 2014). Another study was done in Niger Delta region of Nigeria on some fish ponds. The study showed high level of feacal coliforms, Escherichia coli and some pathogenic bacteria were isolated (Njoku *et al*, 2015). In Kenya Samburu District surface water sources were all contaminated with feacal matters, the conclusion was made due to the presence of feacal coliforms and Escherichia coli (Cheluget 2011).

2.4 SADC Region Surface Water bacteriological Quality Situation

Surface water bacteriological contamination is also common in Sadc region. Bacteriological contamination was recorded in main rivers feeding the Katse Dam in Lesotho (Mathebula, 2015). In Buffalo river Eastern Cape Province of South Africa, the research was conducted on the bacteriological quality and it was discovered that the river highly feacally contaminated (Chigor *et al,* 2012). In Durban, South Africa the microbiological assessment was conducted on Palmiet and Isipingo and it was observed that both rivers were highly contaminated (Sithebe 2016).

2.5 Zambia Surface Water bacteriological Quality Situation

Improper land use, indiscriminate waste disposal, emissions from excessive use of agricultural and domestic and industrial effluents are some of the cited causes of surface water pollution in Zambia (Petersson, 2005) . In Ndola, the study was done on surface water sources and it indicated that all samples collected from surface water were positive with feacal matters (Liddle, 2014). Pollution studies have been conducted on Kafubu River leaving the water body with no bacteriological contamination status data.

CHAPTER THREE

3. MATERIALS AND METHODS

The purpose of this chapter is to discuss the research methods and materials for this research study. The chapter contains the study area location and description, location, description, research design and data analysis of the study.

3.1 Study Area

3.2.1 Location

Kafubu River is one of the main watersheds in Ndola district, Zambia. Ndola District has a population of approximately 455,194 people (Central Statistical Office, 2011). It lies just 10 kilometres from Democratic Republic of Congo border. The river under study is located in the town of Ndola district and passes through many townships on the southern part of the city up to the point of raw water abstraction by Kafubu water and Sewerage Company (KWSC) for water supply to Residents of the city. Kafubu River serves as a source of domestic water usage, agricultural, industrial, fishing and recreational water source for its population. Despite its important roles and services, the River has been facing a number of anthropogenic activities and it is important to study its bacteriological water quality for public health risk. Bacteriological water quality assessment of surface water is critical as it can be one way of giving information to the public about water quality and its importance in reducing potential public health risks (Kumar *et al*, 2018).

Ndola is the third largest city in Zambia, with the population of 455,194 (CSO, 2010).It is the industrial and commercial center of the Copperbelt, Zambia's copper-mining region, and capital of Copperbelt Province. It lies just 10km from the border with DR Congo. The city formed in 1904 by John Edward just six months after Livingstone, making it the second oldest colonial-era town of Zambia. It started as a boma and trading post, which laid its foundations as an administrative and trading centre today. It is located at 12° 58´00°S and 28°38´00°E in the Copperbelt Province (**Figure 2)**

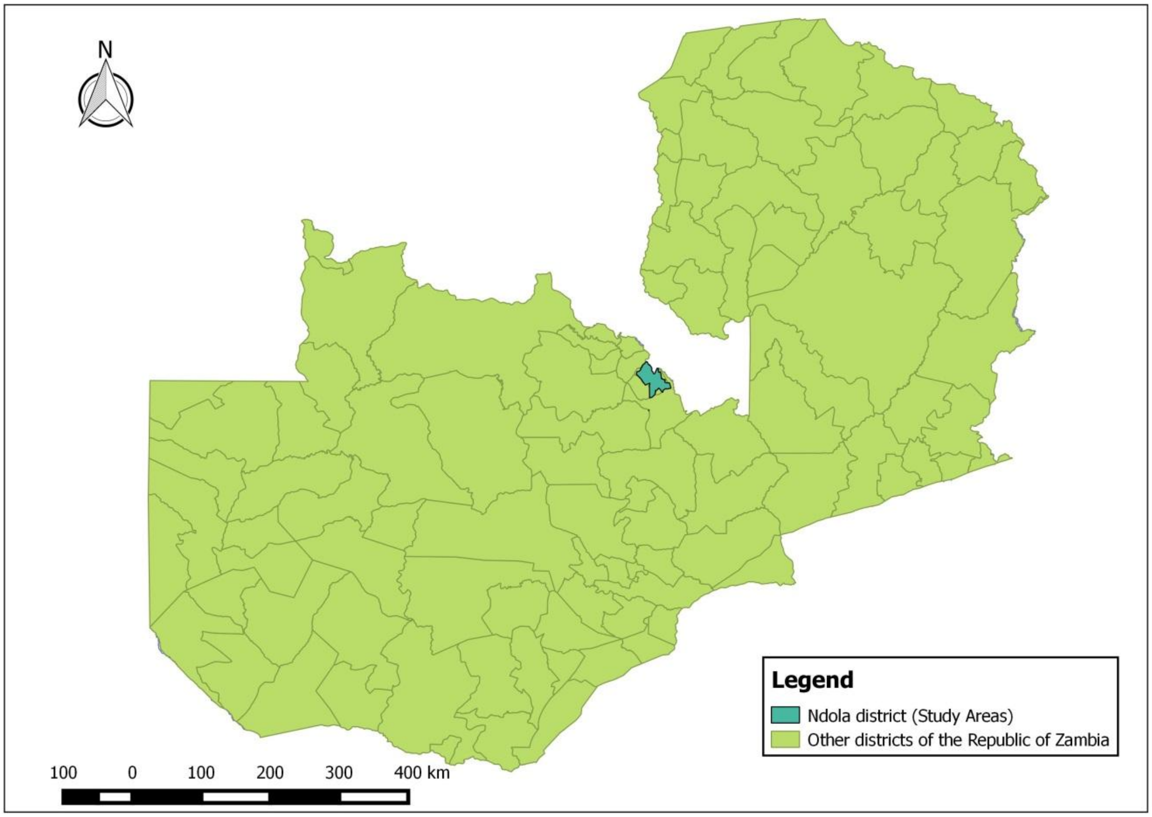

Figure 2: Map of Zambia showing the location of Ndola District (Study Area)

3.2.2 Description

Kafubu River is one of the main fresh watersheds in Ndola district, Zambia. The river under study is located in the town of Ndola district and passes through many townships on the southern part of the city up to the point of raw water abstraction by Kafubu water and Sewerage Company (KWSC) for water supply to Residents of the city (**Figure 3).**

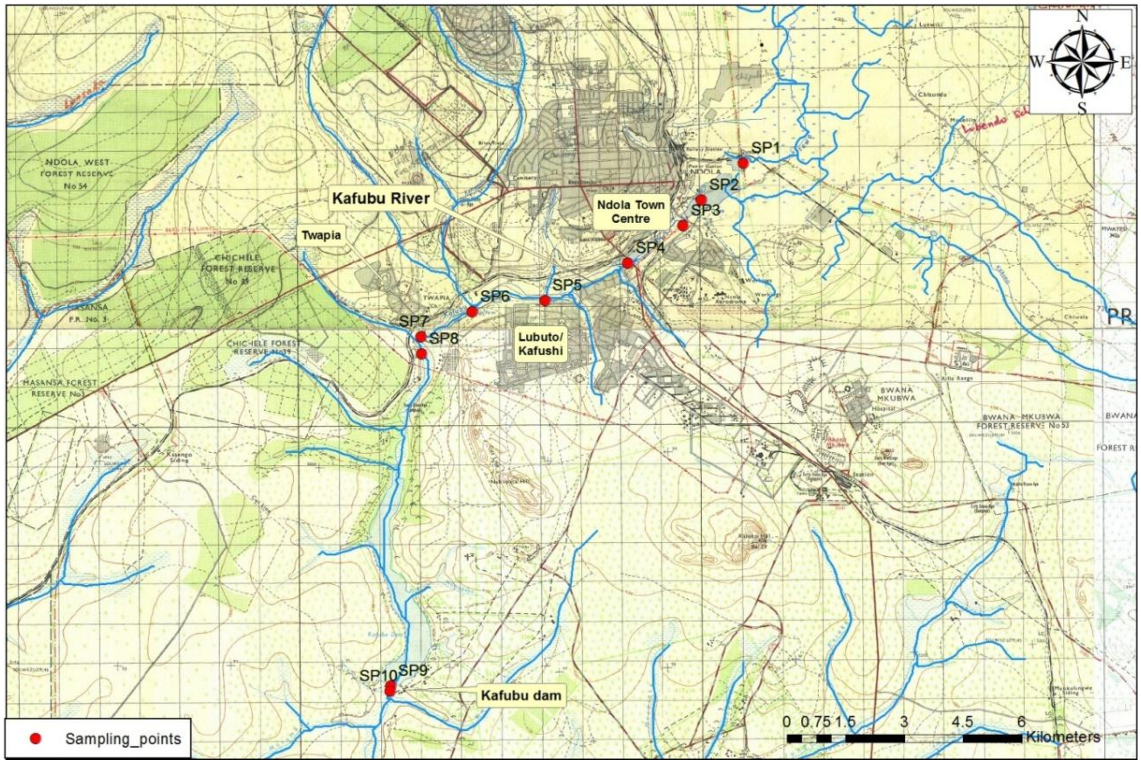

Figure 3: Distribution of sampling points on the Kafubu River

3.3 Research Design

The research design was set as following;

3.3.1 Data Collection

Sampling points (SPs) were systematically identified on Kafubu River from upstream to down-stream. Ten (10) sampling points were identified named as SP1, SP2, SP3, SP4, SP5, SP6, SP7, SP8, SP9 and SP10. Coordinates were taken for each sampling point (table 1) and plotted as shown in Figure 3.

Table 1: Global Position System Coordinates for Sampling Points.

Sampling Point	Description of Location and Activity Types	South	East
1	Chilanga Cement Road- Fishing, and swimming	-12.96223º	28.66973 º
2	Boating Club- boating, swimming and fishing	-12.97067 º	28.66016 º
3	Itawa Bridge- farming, fishing, car washing and swimming	-12.97649 º	28.65583 º
4	Nkana Road Bridge- Farming, Fishing and Re-pumping station	-12.98517 º	28.64322 º
5	Kabushi Bridge- Fishing, farming, swimming and effluent discharge	-12.99372 º	28.62414 º
6	Mbaya Bridge- Fishing, farming and swimming	-12.99633 º	28.60748 º
7	Twapia Bridge- farming, fishing, car washing, swimming and domestic use	-13.00202 º	28.59578 º
8	Bunga- Fishing, farming, swimming and effluent discharge	-13.00598 º	28.59579 º
9	Kafubu Dam - fishing and water abstraction for treatment	-13.08204 º	28.58871º
10	Kamafwesa area- Fishing, swimming and domestic use	-13.08327 º	28.58859 º

3.3.2 Target Population

According Mugenda and Mugenda (1999) describe target population as that population to which a researcher wants to get the information of the study. The target population in Kafubu River was all the sampling point identified. This would be used as a sampling frame from which a representative samples were collected for the research.

3.3.3 Sampling Frequency

Each sampling point was visited ten (10) times and ten samples were collected from each point, which resulted into hundred (100) samples collected for the study in two (2) months time from October to November 2017.

3.3.4 Water Sampling Method

Grab samples of water were collected from the ten (10) sampling points on the Kafubu River using a sampling scoop tied to 2.5 metres steel rope (**Figure 4**). Borosilicate 500 ml glass bottles were used during sample collection (**Figure 5**). Sample bottles were sterilized for every batch to avoid sample contamination. MethylatedSpirit and cotton wool were used to flame the sampling scoop to maintain integrity and avoid cross contamination from one sampling point to another during sampling process. Samples were put in ice parks during transportation to TDRC and KWSC laboratories for analysis.

Figure 4: sampling scoop with 2.5m rope left and cooler box right used during sample collection

Figure 5: sampling process in progress at sp-7

3.3.5 Laboratory Analysis Method

Quantitative bacteriological analysis of all water samples was done. Standard membrane filtration method (APHA 1999) was used for counting of total coliforms, feacal coliforms and Escherichia coli in water samples. 0.4µm pore size and 47mm diameter filter membrane type were used (**Figure 6**). M-Endo Agar Less and M-FC Agar were used. Qualitative sample analysis was done for pathogenic organisms. This analysis was conducted at TDRC microbiology laboratory. Two selective media were used for this particular analysis namely; Xylose-Lysine-Desoxycholate Agar (XLD) for isolation of *Salmonella* and *Shigella* in water samples. Thiosulfate Citrate Bile Salts Sucrose Agar (TCBS) for the isolation *Vibrio cholera*.

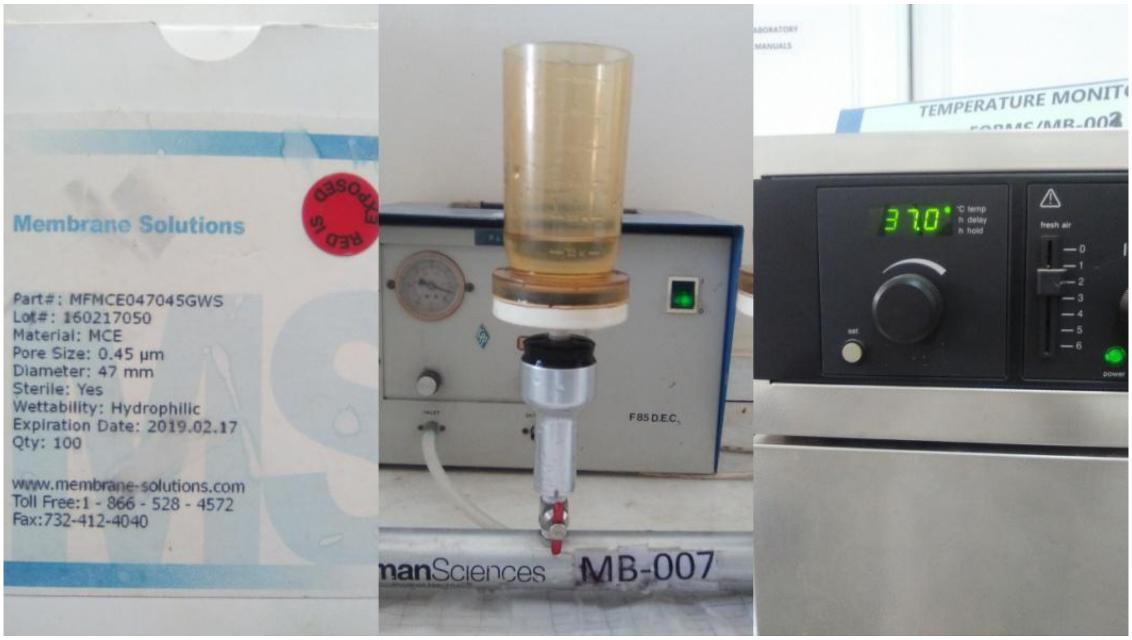

Figure 6: filters used left, filtration unit centre and the incubator right

3.3.6 Statistical Analysis

The quantitative data collected were subjected to descriptive statistical analysis using the means. In addition, geostatistcal analysis was used to model the total coliforms, feacal coliforms and *Escherichia coli* concentration level along the sampled river section. The pathogenic bacteria (*Salmonella, Shigella and Vibrio cholerae*) were estimated simple measure of frequency.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1 Results

This chapter presents the research findings on bacteriological concentration level of contamination in the Kafubu River in Ndola, Zambia for public health risk.

4.1.1 Bacteriological Concentrations and Presence of Pathogenic Bacteria

From the ten sampling points identified, 100 water samples were collected and analyzed. The general water quality of the river was not okay. All the samples were positive with total coliforms, feacal coliforms, *Escherichia coli* and the presence of pathogenic bacteria growth was observed. This indicated that the sampled section of the river was faecal contaminated. The detailed results are shown below:

4.1.1.1 Bacteriological Concentrations

The means of the total coliforms (TC), feacal coliforms (FC) and the *Escherichia coli* (E. coli) were presented in (**Figure.** 7). The minimum mean for TC was 2497 cfu/100ml and the maximum mean was 17101 cfu/100ml of water sample. The minimum mean for FC was 925cfu/100ml and the maximum mean was 13083 cfu/100ml of water sample. The minimum and the maximum means of FC were far from the freshwater quality standard limits and this confirmed the high concentration level FC in Kafubu River. The minimum mean for *E. coli* was 27 cfu/100ml and the maximum was 4302 cfu/100ml of water sample. The means from sampling points 1, 2 and 4 were in conformity with the freshwater quality standard limits for *E. coli* and sampling points 3 and 10 were partially in conformity with the freshwater quality standard limits as shown in figure 7. Sampling points 5,6,7,8 and 9 confirmed high concentration level of *E.coli* in the Kafubu River.

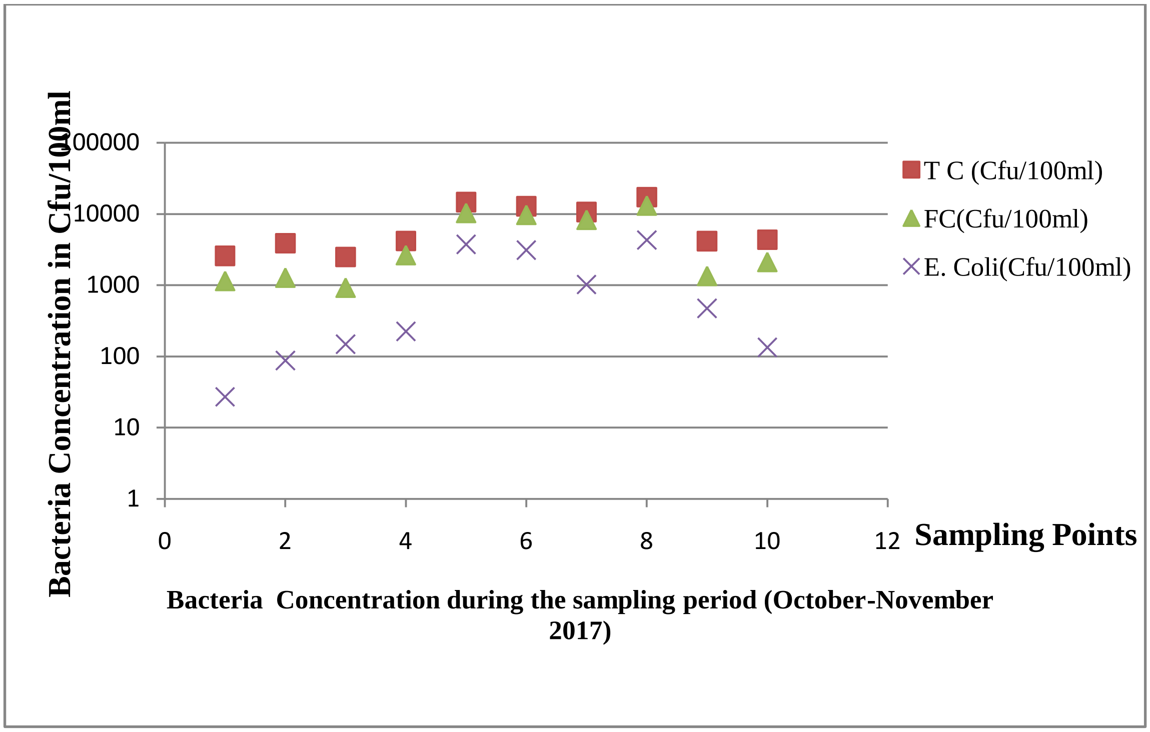

Figure 7: the mean concentration levels of TC, FC and E. coli for all ten sampling points**.**

4.1.1.2 Presence of Pathogenic Bacteria

The presence in percentage of the three pathogenic bacteria in Kafubu River was examined and the findings were shown in Figure 8. *Salmonella*, *Shigella* and *Vibrio cholerae* were dominantly present in sampling points 4, 5,6,7,8 and 9. Sampling points 5, 6 and 8 scored the highest percentage being 100% for all the three pathogenic bacteria. Sampling points 4 and 9 scored 30% *Salmonella*, *Shigella*, and 20% for *Vibrio cholerae* respectively. Sampling point 7 scored 90% for both *Salmonella* and *Shigella* and 80% for *Vibrio cholerae.* Sampling point 1, 2, 3 and 10 recorded 0%.

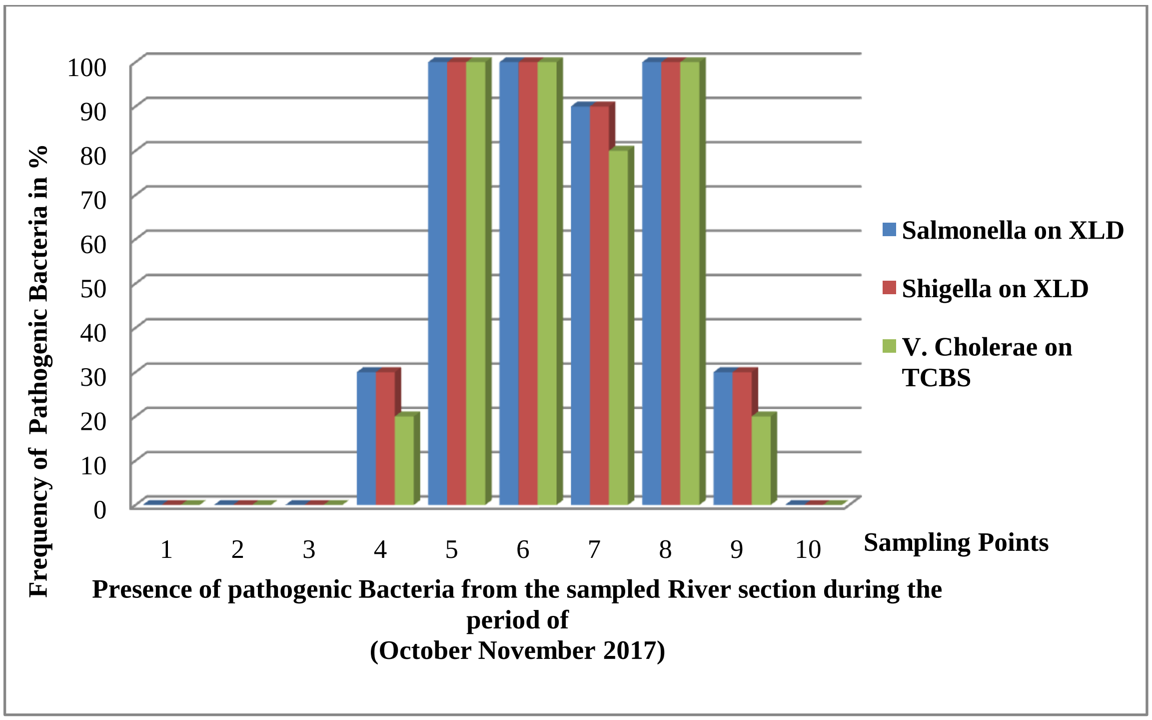

Figure 8: presence of pathogenic bacteria in ten sampling points

4.1.2 Evaluation of total coliforms, faecal coliforms and *Escherichia coli* in the Kafubu River

The evaluation of bacteriological concentration of total coliforms, faecal coliforms and *Escherichia coli* against the threshold for the ambient state of water quality in the Kafubu River was done and the results were tabulated in (table 2).

Table 2: Summary of the Means for three types of bacteria measured against the threshold for the ambient state of water quality

SP	TC(Cfu/100ml)	FC(Cfu/100ml)	E.coli(Cfu/100m)	USEPA freshwater Quality natural limits for FC (Cfu/100ml)	USEPA freshwater Quality natural limits for E.coli (Cfu/100ml)
1	2582	1150	27	200	126
2	3887	1278	88	200	126
3	2497	925	149	200	126
4	3901	2230	225	200	126
5	14628	10309	3752	200	126
6	12783	9698	3112	200	126
7	10633	8269	1024	200	126
8	17101	13083	4302	200	126
9	4145	1351	474	200	126
10	4344	2120	134	200	126

The confidence level of the mean was at 95%. TC= total coliforms, FC = feacal coliforms, E.coli = *Escherichia Coli*, SP= Sampling Point and Cfu=Colony forming unit

Using the summary of the means, it was found that all sampling points for feacal coliforms were far above the ambient state of water quality. For *Escherichia coli*, only two sampling points were in conformity with the ambient state of water quality as shown in table 2.

4.1.3 Spatial Distribution of Bacteria for the sampled section of the Kafubu River

The bacteria in question for spatial distribution modeling were total coliforms, feacal coliforms and *Escherichia coli* for the sampled section of the Kafubu River. The examined and analyzed data are shown in figures 9, 10 and 11 respectively. The field contours were used to clearly show the spatial distribution concentration levels of the total coliforms, feacal coliforms and *Escherichia coli* of the sampled section of Kafubu River.

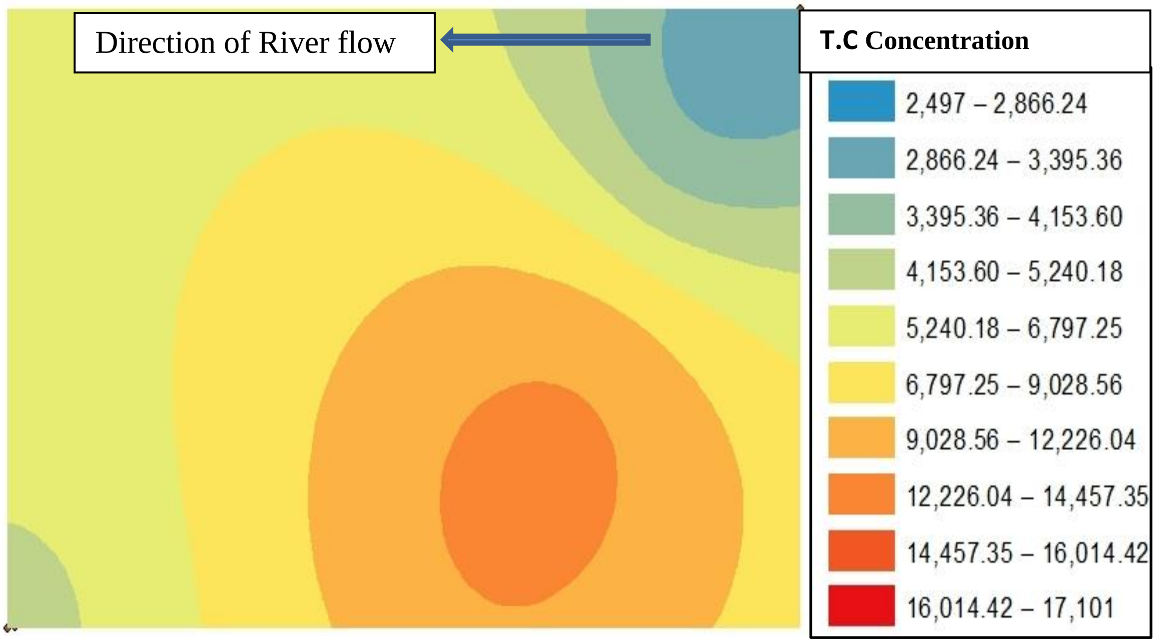

Figure 9: Total Coliforms spatial distribution of the concentration level of contamination

The arrow in Figure 9 is showing the River flow direction. The change in color is showing the change in concentration level of contamination in the Kafubu River. The blue color at sampling point 1 is showing the lowest concentration and the red color showing the highest concentration of the total coliforms in the River.

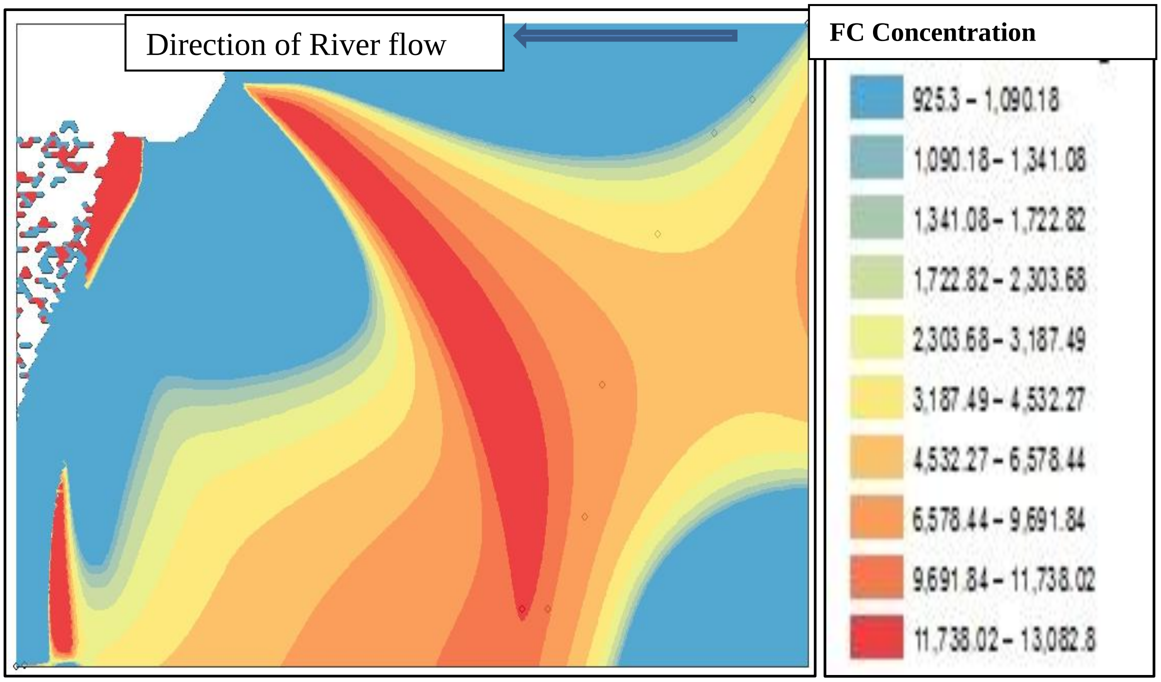

Figure 10: feacal coliforms spatial distribution of the concentration level of contamination

The arrow in Figure 10 is showing the River flow direction. The change in color is showing the change in concentration level of contamination of feacal coliforms in the Kafubu River. The blue color is showing the lowest concentration and the red color showing the highest concentration of the feacal coliforms in the River.

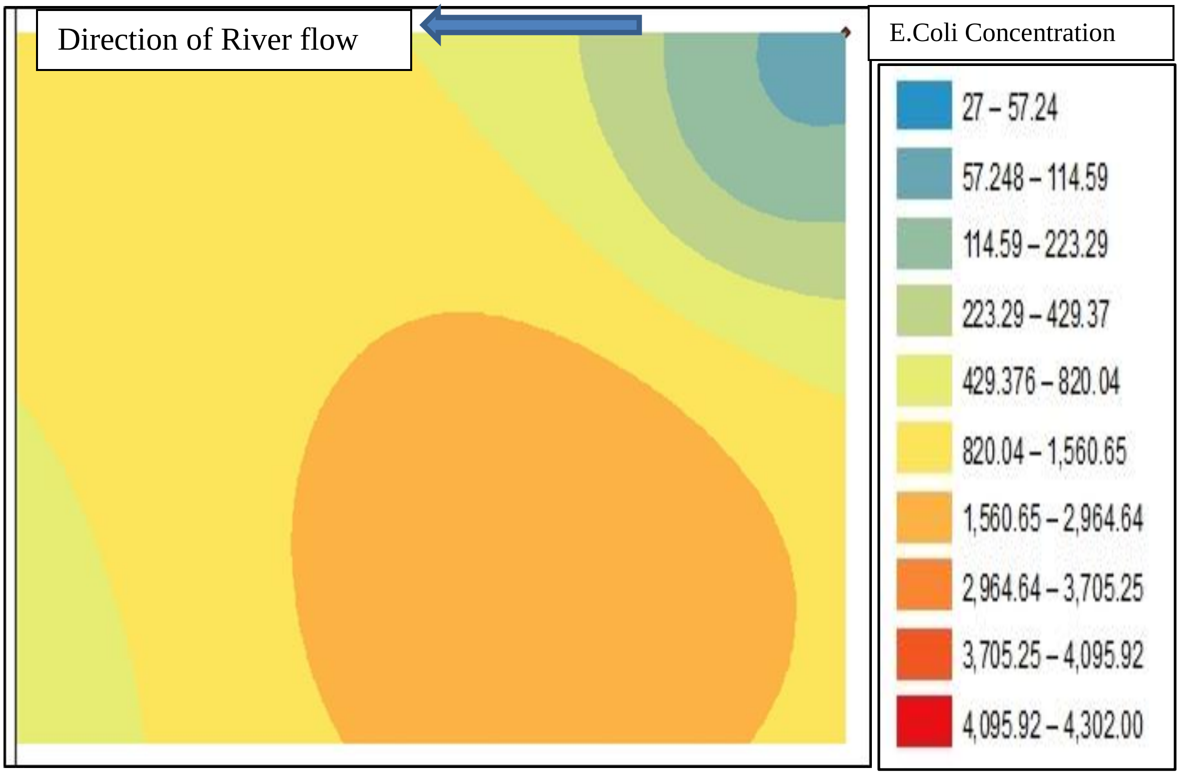

Figure 11: Escherichia Coli spatial distribution of the concentration level of contamination

The arrow in Figure 11 is showing the River flow direction. The change in color is showing the change in concentration level of contamination of *Escherichia Coli* in the Kafubu River. The blue color is showing the lowest concentration and the red color showing the highest concentration of the *Escherichia coli* in the River. The deep red color is not seen in Figure 11 due to being overlaid.

4.2 Discussion

Sampling points which were in the sewage effluent discharge range recorded high concentration level of total coliforms, feacal coliforms and *Escherichia coli* compared to sampling points which were out of sewage effluent discharge range. Sampling points 4, 5,6,7,8 and 9 showed the presence of pathogenic bacteria due to the fact that these points were within the sewage effluent discharge perimeters. The presence of the pathogenic bacteria confirmed with high concentration levels of total coliforms, feacal and *Escherichia coli* in the same sampling points. This indicates the high potential public health risks to Kafubu River water users and it is a biological health hazard.

Total coliforms were observed to be slight higher in most of the sampling points due to that they are so many activities along the river that could contribute high load. All the sampling points for feacal coliforms were far above the ambient state of water quality because of the sewage effluent discharge. For *Escherichia coli*, only two sampling points were in conformity with the ambient state of water quality as shown in table 2.

The spatial distribution of bacteria (total coliforms, feacal coliforms and *Escherichia coli*) concentration level of contamination modeling showed that the contamination was more in points which were in effluent discharge range. The colors of the field contours were corresponding with the concentration levels for each sampling point.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The Bacteriological water quality assessment of the Kafubu River in Ndola, Zambia for public health risk study has shown that the sampled section is highly contaminated with feacal matters. The point sources pollution being domestic Sewerage effluent discharged by Kafubu Water and Sewerage Company into the River and industrial effluents and non-point sources such domestic activities, agricultural, fishing and untreated feacal matters from septic tanks from those house located near the River have been some of the reasons for the Kafubu River water contamination. The study also showed that the highly polluted sampled points are the most frequently visited areas by Kafubu River water users. This indicates high health risks of water-borne diseases outbreak to these people who come in contact of this contaminated water body. Despite not having empirical data on the health status of the Kafubu River water users, the results from the study indicate that the water is capable of causing acute diarrhea, skin rashes and sore throats to those who swim and fish in this water body. From the results obtained, the study also suspects some high level of bacteria concentration in catfish found in the sampled River section.

5.2 Recommendations

Based on the study outcomes, the researcher suggested the following recommendations to mitigated further deterioration of the River and its aquatic lives and reduces the public health risk in Kafubu River.

It is recommended that routine monitoring of this water body is put in place by WARMA, ZEMA and Ministry of Water Development, Sanitation and Environment Protection to insure proper water quality record that can help in decision-making.

It is again recommended that ZEMA must revise the current permissible bacteriological load limits in effluent that can help reduce the load to the level the River can handle during natural River purification.

The recommendation was made that WARMA, ZEMA and Ministry of Water Development, Sanitation and Environment Protection must come up with national freshwater bacteriological load quality standard limits in these Rivers.

Classification of the Rivers according to their services they offer to the communities must be done to further enforce the environmental protection laws in the country.

Integrated Water Resources Management (IWRM) policies must implemented at local and national levels to safeguard our water sources from pollution of this kind.

It is recommended that a research is conducted on the catfish in Kafubu River sampled section to ascertain its quality where bacteriological load is concerned.

The District and Provincial public Health Office must carry out a survey on some of water-borne diseases that acutely occur in the district if they are connected to Kafubu River water usage.

It is further recommended that KWSC to work on their sewerage network to reduce on the uncontrolled raw sewerage that can find its way in the River through the non source points.

It is further recommended that the Ministry of Water Development, Sanitation and Environment Protection fund KWSC to come up with the project to connect the houses along the River to the sewerage network to stop non-point sources of feacal contaminations.

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7. APPENDICES

Appendix 1: Table of Laboratory Results for all sampling Points

ID N0.	SP ID	BATCH	DATE COLLECTED	DATE ANALYZED	DATE RESULT	T C cfu/100ml	F.C cfu/100ml	E.coli cfu/100ml
1	1	1	25-Oct-17	26-Oct-17	27-Oct-17	1800	1200	15
2	2	1	25-Oct-17	26-Oct-17	27-Oct-17	1360	1170	10
3	3	1	25-Oct-17	26-Oct-17	27-Oct-17	1900	1300	32
4	4	1	25-Oct-17	26-Oct-17	27-Oct-17	1742	300	450
5	5	1	25-Oct-17	26-Oct-17	27-Oct-17	13200	5600	1002
6	6	1	25-Oct-17	26-Oct-17	27-Oct-17	1300	600	8
7	7	1	25-Oct-17	26-Oct-17	27-Oct-17	980	530	510
8	8	1	25-Oct-17	26-Oct-17	27-Oct-17	12700	4300	1508
9	9	1	25-Oct-17	26-Oct-17	27-Oct-17	3800	1280	320
10	10	1	25-Oct-17	26-Oct-17	27-Oct-17	17200	11808	107

11	1	2	29-Oct-17	30-Oct-17	31-Oct-17	1700	1240	35
12	2	2	29-Oct-17	30-Oct-17	31-Oct-17	1360	480	25
13	3	2	29-Oct-17	30-Oct-17	31-Oct-17	1800	784	525
14	4	2	29-Oct-17	30-Oct-17	31-Oct-17	3500	2000	700
15	5	2	29-Oct-17	30-Oct-17	31-Oct-17	15000	13780	4000
16	6	2	29-Oct-17	30-Oct-17	31-Oct-17	15600	12800	4800
17	7	2	29-Oct-17	30-Oct-17	31-Oct-17	14500	12112	300
18	8	2	29-Oct-17	30-Oct-17	31-Oct-17	14000	12700	5000
19	9	2	29-Oct-17	30-Oct-17	31-Oct-17	1680	1400	2500
20	10	2	29-Oct-17	30-Oct-17	31-Oct-17	1900	1140	500
21	1	3	31-Oct-17	1-Nov-17	2-Nov-17	1900	1300	25
22	2	3	31-Oct-17	1-Nov-17	2-Nov-17	3600	1620	20
23	3	3	31-Oct-17	1-Nov-17	2-Nov-17	3480	1160	130
24	4	3	31-Oct-17	1-Nov-17	2-Nov-17	2000	1630	30
25	5	3	31-Oct-17	1-Nov-17	2-Nov-17	17000	13830	3200
26	6	3	31-Oct-17	1-Nov-17	2-Nov-17	20000	15200	2000
27	7	3	31-Oct-17	1-Nov-17	2-Nov-17	16500	13620	400
28	8	3	31-Oct-17	1-Nov-17	2-Nov-17	24600	21200	2500
29	9	3	31-Oct-17	1-Nov-17	2-Nov-17	1800	1440	320
30	10	3	31-Oct-17	1-Nov-17	2-Nov-17	1850	1260	200

31	1	4	5-Nov-17	6-Nov-17	7-Nov-17	460	100	10
32	2	4	5-Nov-17	6-Nov-17	7-Nov-17	2450	1980	10
33	3	4	5-Nov-17	6-Nov-17	7-Nov-17	2000	1540	20
34	4	4	5-Nov-17	6-Nov-17	7-Nov-17	3100	1820	50
35	5	4	5-Nov-17	6-Nov-17	7-Nov-17	16500	13400	3500
36	6	4	5-Nov-17	6-Nov-17	7-Nov-17	18100	14000	2510
37	7	4	5-Nov-17	6-Nov-17	7-Nov-17	900	730	200
38	8	4	5-Nov-17	6-Nov-17	7-Nov-17	14700	13600	4000
39	9	4	5-Nov-17	6-Nov-17	7-Nov-17	2900	1400	500
40	10	4	5-Nov-17	6-Nov-17	7-Nov-17	3300	1600	200
41	1	5	7-Nov-17	8-Nov-17	9-Nov-17	1900	1200	1
42	2	5	7-Nov-17	8-Nov-17	9-Nov-17	1450	520	20
43	3	5	7-Nov-17	8-Nov-17	9-Nov-17	1800	90	30
44	4	5	7-Nov-17	8-Nov-17	9-Nov-17	1600	110	4
45	5	5	7-Nov-17	8-Nov-17	9-Nov-17	19000	14300	5500
46	6	5	7-Nov-17	8-Nov-17	9-Nov-17	23000	14800	5000
47	7	5	7-Nov-17	8-Nov-17	9-Nov-17	17400	13200	1000
48	8	5	7-Nov-17	8-Nov-17	9-Nov-17	18900	13900	6000
49	9	5	7-Nov-17	8-Nov-17	9-Nov-17	2400	1600	12
50	10	5	7-Nov-17	8-Nov-17	9-Nov-17	800	56	10

51	1	6	12-Nov-17	13-Nov-17	14-Nov-17	2190	1220	6
52	2	6	12-Nov-17	13-Nov-17	14-Nov-17	4380	1920	12
52	3	5	7-Nov-17	8-Nov-17	9-Nov-17	1800	90	30
54	4	6	12-Nov-17	13-Nov-17	14-Nov-17	16200	13000	15
55	5	6	12-Nov-17	13-Nov-17	14-Nov-17	490	80	20
56	6	6	12-Nov-17	13-Nov-17	14-Nov-17	930	56	3
57	7	6	12-Nov-17	13-Nov-17	14-Nov-17	2000	1500	25
58	8	6	12-Nov-17	13-Nov-17	14-Nov-17	15600	12500	10
59	9	6	12-Nov-17	13-Nov-17	14-Nov-17	7300	1620	20
60	10	6	12-Nov-17	13-Nov-17	14-Nov-17	4500	1880	12
61	1	7	13-Nov-17	14-Nov-17	15-Nov-17	3000	1250	20
62	2	7	13-Nov-17	14-Nov-17	15-Nov-17	6600	1360	50
63	3	7	13-Nov-17	14-Nov-17	15-Nov-17	1680	1420	70
64	4	7	13-Nov-17	14-Nov-17	15-Nov-17	1480	1300	150
65	5	7	13-Nov-17	14-Nov-17	15-Nov-17	11100	8800	8000
66	6	7	13-Nov-17	14-Nov-17	15-Nov-17	13400	11600	6000
67	7	7	13-Nov-17	14-Nov-17	15-Nov-17	19000	13200	20000
68	8	7	13-Nov-17	14-Nov-17	15-Nov-17	23600	12800	10000
69	9	7	13-Nov-17	14-Nov-17	15-Nov-17	1160	160	200
70	10	7	13-Nov-17	14-Nov-17	15-Nov-17	1000	400	100

71	1	8	14-Nov-17	15-Nov-17	16-Nov-17	3260	1240	10
72	2	8	14-Nov-17	15-Nov-17	16-Nov-17	8000	1300	30
73	3	8	14-Nov-17	15-Nov-17	16-Nov-17	1350	990	300
74	4	8	14-Nov-17	15-Nov-17	16-Nov-17	1700	670	50
75	5	8	14-Nov-17	15-Nov-17	16-Nov-17	26000	14000	800
76	6	8	14-Nov-17	15-Nov-17	16-Nov-17	10000	1020	500
77	7	8	14-Nov-17	15-Nov-17	16-Nov-17	14800	12200	300
78	8	8	14-Nov-17	15-Nov-17	16-Nov-17	17800	13100	2800
79	9	8	14-Nov-17	15-Nov-17	16-Nov-17	5300	1620	20
80	10	8	14-Nov-17	15-Nov-17	16-Nov-17	1900	140	15
81	1	9	19-Nov-17	20-Nov-17	21-Nov-17	4120	1280	30
82	2	9	19-Nov-17	20-Nov-17	21-Nov-17	3600	1110	200
83	3	9	19-Nov-17	20-Nov-17	21-Nov-17	1760	211	50
84	4	9	19-Nov-17	20-Nov-17	21-Nov-17	3500	2000	200
85	5	9	19-Nov-17	20-Nov-17	21-Nov-17	19000	13000	7000
86	6	9	19-Nov-17	20-Nov-17	21-Nov-17	15300	13300	6300
87	7	9	19-Nov-17	20-Nov-17	21-Nov-17	1350	1300	500
88	8	9	19-Nov-17	20-Nov-17	21-Nov-17	14900	12800	5200
89	9	9	19-Nov-17	20-Nov-17	21-Nov-17	6000	1180	450
90	10	9	19-Nov-17	20-Nov-17	21-Nov-17	3100	1230	100

91	1	10	20-Nov-17	21-Nov-17	22-Nov-17	5492	1468	120
92	2	10	20-Nov-17	21-Nov-17	22-Nov-17	6074	1294	500
93	3	10	20-Nov-17	21-Nov-17	22-Nov-17	7402	1668	300
94	4	10	20-Nov-17	21-Nov-17	22-Nov-17	6988	3600	600
95	5	10	20-Nov-17	21-Nov-17	22-Nov-17	8992	6304	4500
96	6	10	20-Nov-17	21-Nov-17	22-Nov-17	10204	13600	4000
97	7	10	20-Nov-17	21-Nov-17	22-Nov-17	18400	14000	5000
98	8	10	20-Nov-17	21-Nov-17	22-Nov-17	14208	13928	6000
99	9	10	20-Nov-17	21-Nov-17	22-Nov-17	9112	1812	400
100	10	10	20-Nov-17	21-Nov-17	22-Nov-17	7894	1688	100

Appendix 2: Laboratory Pictures

Figure 12: water samples in sterile glass bottles in the Lab

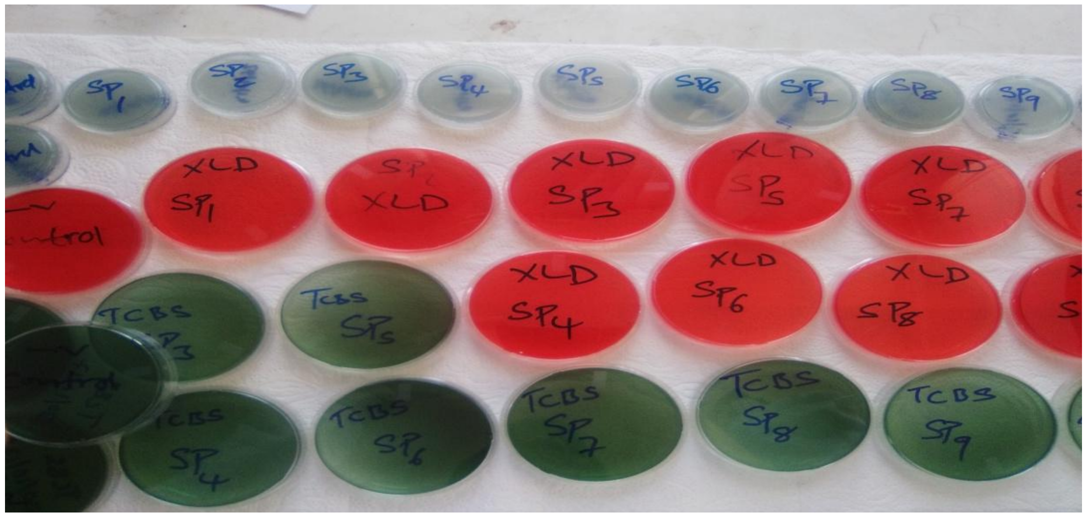

Figure 13: Types media used in qualitative sample analysis, Red = XLD for SS and Green= TCBS for *V. Cholerae*.

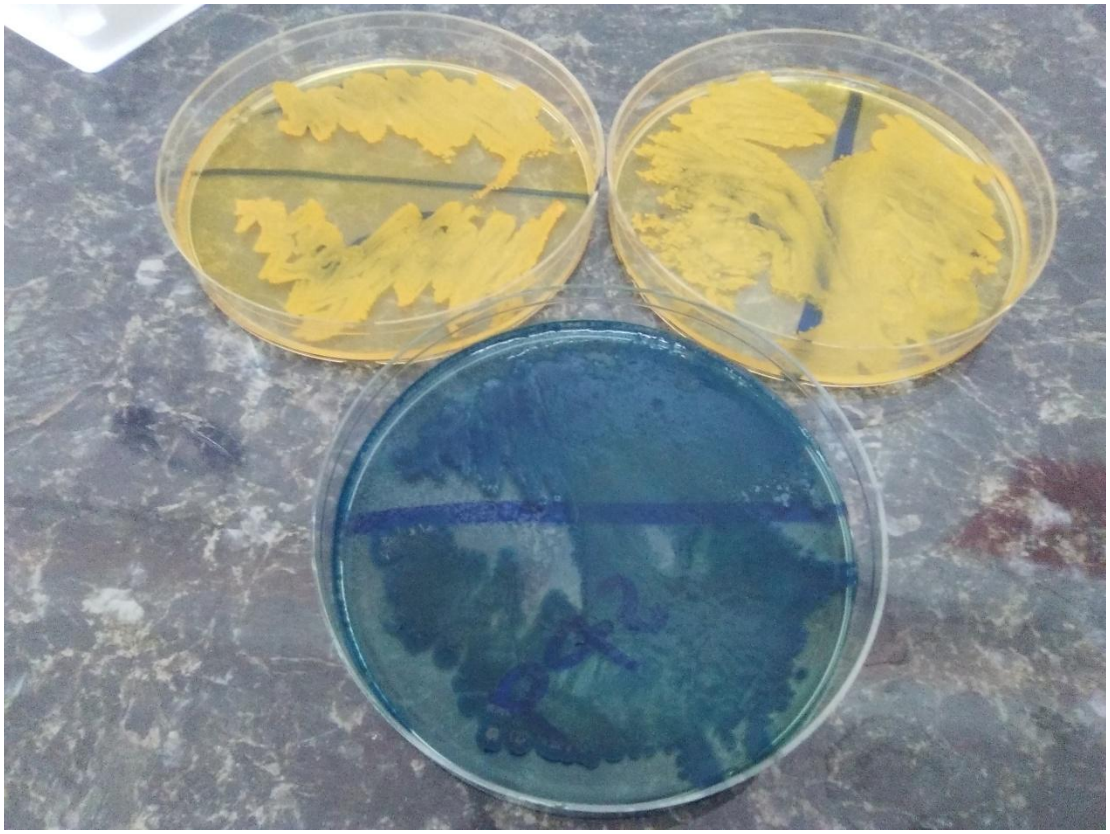

Figure 14: the cultured plate for *Vibrio Cholerae* on TCBS in Yellow

Figure 15: the researcher with samples ready for incubation

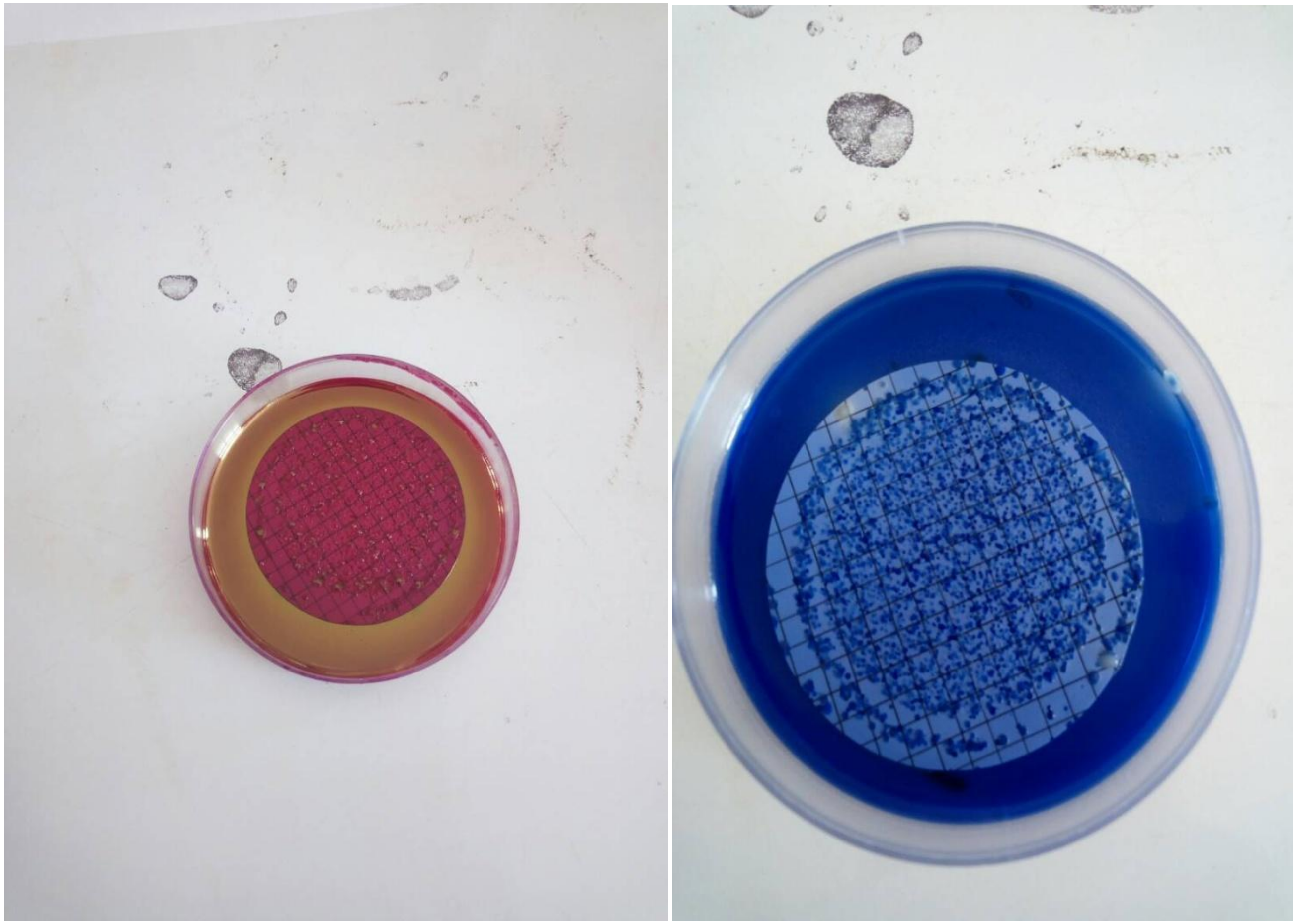

Figure 16: TC Red to red-black colonies with a golden-green metallic sheen colonies and FC blue colonies

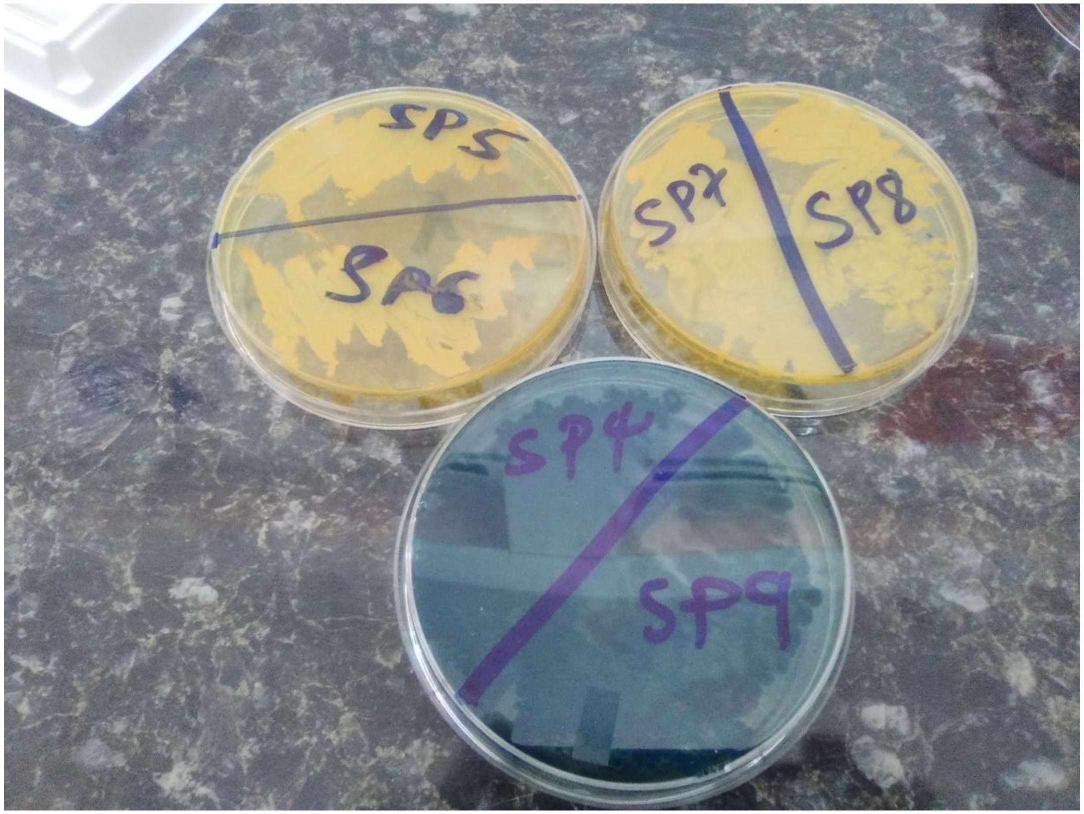

Figure 17: cultured plate for *Vibrio Cholerae* on TCBS for SP 5, SP 6, SP 7 and SP 8 in Yellow

Black spots indicating production of Hydrogen Sulphide by *Salmonella*

Yellowish color showing the *Escherichia Coli* on XLD

Reddish color Showing the presence of *Shigella*

Figure 18: presence of *Salmonella* and *Shigella* on XLD

Figure 19: negative control plate and the positive water sample plate for Vibrio Cholerae on TCBS

Appendix 3: Field Pictures

Figure 20: Catfish and Crabs caught at SP-5

Figure 21: breams caught at SP -9

Figure 22: men catching catfish and crabs using bear hands at SP-5

Figure 23: two school going boys fishing with the Mosquito net at SP 8

Figure 24: people washing and swimming at SP-7

Figure 25: six school going boys swimming at SP -5

Figure 26: women watering their okra plants at SP-6

Figure 27: boys fishing using hooks known as ukuloba in local language at SP-3

Figure 28: boys and girls swimming at SP-7