WASTEWATER DISPOSAL STATUS IN MALAWI BASED ON THE CITY OF BLANTYRE AS A CASE STUDY

MSC. INFRASTRUCTURE DEVELOPMENT AND MANAGEMENT THESIS

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MSc. Infrastructure Development and Management Thesis

By

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DECLARATION

I, **George Wilson Francis Chidulo**, declare that this is my own work. I have not presented or submitted it elsewhere for any award, and, I have acknowledged all sources of additional information.

Signature:_______________________________________Date:__________________________

CERTIFICATE OF APPROVAL

We, the undersigned, certify that we have read and hereby recommend for acceptance by the University of Malawi a thesis titled 'Wastewater disposal status in Malawi based on the city of Blantyre as a case study'

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Head of Department : ___________________________________

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Date : ___________________________________

DEDICATION

This thesis is dedicated to my wife Kumbukani and children: Promise, Pemphero and Prince. Your support gave me courage to complete this programme against all odds. You are a wonderful team.

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My wife and our three children, thank you for enduring my absence. Your patience and perseverance gave me courage and strength to fight on and stretch myself beyond the limit in times of extreme lack of financial resources needed to support this research.

To God Almighty, thank you for the grace and mercy that enabled me to study for a Master's degree. I shall forever be grateful to God for this. I have seen His involvement in this work.

ABSTRACT

Wastewater disposal study was conducted in Blantyre City to establish status of wastewater disposal and determine volume of wastewater generated per residential land use category, and assess pollution impact of effluent from wastewater treatment facilities to the receiving surface water bodies in the city. A survey was carried out from June to August 2018 in twenty (20) areas in the city that were sampled using selective sampling technique. Four study areas were selected within each land use category as follows: Low density areas: Nyambadwe, Namiwawa, Sunnyside and British Central Area (BCA). Medium density areas: Chinyonga, Soche East, Namiyango and Manja. High-density areas: Mbayani, Nkolokoti, Nancholi and Misesa. Traditional housing areas: Ndirande Goliyo, Chilomoni Mthukwa, Manje and Chilobwe. Industrial areas: Makata, Ginnery Corner, Chirimba and Maselema. A multiple response research protocol was randomly administered to one hundred and eighty four (184) respondents within the study areas. The data collected from the survey was analysed using SPSSv20 Software to determine status of wastewater disposal and volume of wastewater released per land use category. Water quality assessment in effluent receiving rivers namely Mudi, Naperi, Limbe and Chirimba was carried out to determine magnitude of water contamination by wastewater. Water samples were collected from upstream and downstream points of a wastewater treatment plant (WWTP) of each river in the month of November 2018 for laboratory tests. Tests for Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Faecal Coliform Bacteria (FCB), Lead (Pb), Cadmium (Cd) and Chromium (Cr) as indicators of wastewater contamination were run and results were compared with standards set by World Health Organization (WHO) and Malawi Bureau of Standards (MBS**).** The results showed that 23.0% of the total wastewater generated in Blantyre City is directly disposed into the sewage system, 33.6% into septic tanks and pit latrines, 37.6% into storm water drains and 5.8% is disposed into rivers. Results further showed that high-density areas generate 14,475 m^3 of wastewater per day, medium density areas 24,897 m^3, low-density areas 43,712 m^3 and informal traditional housing areas generate 9,298 m^3 of wastewater per day. A total of 92,382 m^3 of domestic wastewater is generated per day in the city of Blantyre. The laboratory test results for BOD_5, COD, TSS, FCB, Pb, Cd and Cr in the water samples from the four rivers under study were higher than WHO and MBS guiding limits. Their mean levels differed significantly between the sampling positions (at statistical significance level, $\alpha = 0.05$).

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ABBREVIATIONS AND ACRONYMS

AIT	Asia Institute of Technology
AIDS	Acquired Immuno-deficiency syndrome
APHA	American Public Health Association
BCA	British Central Africa
Cd	Cadmium
BOD_5	Biochemical Oxygen Demand on day 5.
COD	Chemical Oxygen Demand
TSS	Total Suspended Solids
FCB	Faecal Coliform Bacteria
WWTP	Wastewater Treatment Plant
WHO	World Health Organisation
UN	United Nations
NWP	National Water Policy
NSP	National Sanitation Policy
DEA	Department of Environmental Affairs
SDGs	Sustainable Development Goals
THAs	Traditional Housing Areas
TC	Total coliforms
Pb	Lead
Cr	Chromium
UNEP	United Nations Environmental Programme
DEWATS	Decentralised Wastewater Treatment Systems
WSTR	Wastewater Storage and Treatment Reservoirs
WSP	Wastewater Stabilisation Ponds
CW	Constructed Wetlands
UASBs	Up-flow Anaerobic Sludge Blanket reactors
TFR	Total Fertility Rate
IMR	Infant Mortality Rate
SPSS	Statistical Package for Social Scientists

FAS	Iron ammonium sulphate
MBS	Malawi Bureau of Standards
NGO	Non-Governmental Organisation
VIP	Ventilated Improved Pit
ESCAP	Economic and Social Commission for Asia and the Pacific
IWRM	Integrated Water Resources Management
UNWWDR	United Nations World Water Development Report
IDM	Infrastructure Development and Management

CHAPTER 1: BACKGROUND

1.1 Introduction

United Nations (UN)-Water (2015) alludes that wastewater has many definitions. United Nations Environmental Programme (UNEP) and UN-Habitat (2015), and Corcoran et al., (2010) define wastewater as a combination of domestic effluent consisting of black water, which is comprised of excreta, urine and faecal sludge; grey water, which is comprised of kitchen and bathing used water; water from commercial establishments, institutions including hospitals, industrial, storm water and other urban run-off and agricultural effluent.

Wastewater contains many pollutants and contaminants. These include: plant nutrients (for example nitrogen, phosphorous and potassium), pathogenic microorganisms (for instance viruses, bacteria, protozoa and helminths), heavy metals (for example cadmium, chromium, lead, mercury, copper), organic pollutants (polychlorinated biphenyls, polyromantic hydrocarbons, pesticides and biodegradable organics (BOD, COD) and micro-pollutants which include medicines, cosmetics and cleaning agents just to mention a few (UN-Water Analytical Brief, 2015).

Wastewater from various sources needs to be treated to the required standards of effluent quality (Chipofya, 2010) as set by the environmental regulatory agency before discharging to the surface water bodies like rivers, lakes, seas and oceans.

Wastewater treatment is the engineering process in a WWTP that employs physical, biological and chemical processes in order to reduce the concentration of pollutants in wastewater to a harmless or near harmless level in the effluent that can be returned to the water cycle with minimum impact on the environment, or directly reused. This requires that all institutions, industries and houses in all land use categories be connected to the sewerage network that will be collecting wastewater and convey it to WWTPs for treatment before effluent disposal into rivers and streams or to the environment in general.

Policy and legal frameworks as well as institutional arrangements guide wastewater treatment in Malawi. These regulatory instruments are aimed at safeguarding the receiving watercourses from pollution because the water is used for various activities by people downstream for instance; laundry, bathing, or irrigating crops which may be eaten raw (Chipofya, 2010).

Water Resources (Water Pollution Control) Regulations (1978), Water Works Act (1995) and Water Resources Act (2013) provide the main regulatory framework for water resources management and conservation. Other regulatory frameworks are; National Sanitation Policy (NSP, 2008) that stipulates the need for delivery of improved sanitation services in Malawi, and the National Water Policy (NWP, 2005) that ensures availability of water of acceptable quality and quantity for all needs.

In addition to the above, Environmental Management Act (2017), re-enforces establishment of national effluent standards and prescribes measures for pre-treatment of effluent before discharge into the sewage system in Malawi. Environmental Management Authority (EMA) in liaison with relevant lead agencies, namely: MBS, Department of Environmental Affairs (DEA) in the Ministry of Natural Resources, Energy and Environment (MinNREE) are tasked with this responsibility.

Malawi, as a member state of the United Nations (UN), is also obliged to meet the UN Sustainable Development Goals (UN, 2017). Goal number six in the SDGs relates to ensuring availability and sustainable management of water and sanitation for all by 2030.

However, not every house, industry or institution in all land use categories in Blantyre City is connected to the sewerage network. Some wastewater is discharged into septic tanks, latrines, storm water drains and water bodies with due disregard of established wastewater disposal regulations as provided in the Water Resources (Water Pollution Control) Regulations (1978).

1.2 Problem Identification

Malawi's effluent quality standards are as follows: BOD_5, 20 mg/l; COD, 60 mg/l; and TSS[1], 30 mg/l. (MBS, 2015). However, it has been discovered from research studies carried out to assess efficiency of WWTPs in Malawi that quality of effluent discharged in the country does not meet the minimum required standards. It was discovered that effluent discharged from these WWTPs is stronger than recommended by Malawi Bureau of Standards and World Health Organisation (Chipofya, 2010; Kuyeli, 2007; Mtethiwa et al., 2008) (Tables 2.3 and 2.4). In addition, the proportion of wastewater, which is treated in WWTPs before being discharged to the environment in Malawi is as low as 15% (National Environmental Action Plan, 1994), no recent study has been done on this subject since 1994 and that most of the wastewater is disposed and treated through septic tanks and latrines. In Blantyre City, a very small percentage of its population is connected to the sewerage network. Studies indicate that only 16% of the population in the City is connected to the sewerage system while 84% either use pit latrines or septic tanks (Blantyre City Council, 2018). Some untreated wastewater from homes and broken sewerage pipes flows down storm-water drains to the nearest natural drainage system (rivers, streams and valleys). It is feared that surface and ground water resources in Malawi are contaminated by under-treated or untreated sewage, which is continuously being discharged into the ground and surface water bodies.

Chipofya (2010) argues that the total capacity of WWTPs in Blantyre City is only 23.5% such that 76.5% of total generated wastewater is discharged to natural watercourses untreated. He further argues that limited industrial effluent pre-treatment has contributed to severe water quality degradation in the City and the situation poses a threat to the receiving watercourses within the City where the water, further downstream, is used for domestic purposes. However, the author did not elaborate on status of wastewater disposal and quality of water in the City's wastewater receiving surface water bodies. In response to this problem and gap in knowledge, this study determined wastewater disposal status, generation and quality of water in rivers and streams that receive wastewater in all forms in Malawi with a case study of Blantyre City.

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[1] According to World health organization (WHO) **Total dissolved solids** (**TDS**) are inorganic salts and small amounts of organic matter present in solution in water whereas, Total Suspended Solids (**TSS**) are solids in water that can be trapped by a filter.
Wastewater treatment plant (WWTP)

1.3 Research Objective

1.3.1 General Objective

The general objective of the study was to establish wastewater disposal status and levels of water contamination by wastewater in receiving water bodies in Malawi based on the city of Blantyre as a case study.

1.3.2 Specific Objectives

The following were the specific objectives of the study:

1.3.2.1 Explore how wastewater is managed in terms of disposal in Blantyre City.

1.3.2.2 Determine volume of wastewater released per residential land use category in Blantyre City.

1.3.2.3 Assess pollution impact of wastewater treatment facilities in the city of Blantyre by conducting laboratory tests on water in effluent receiving rivers in the City in terms of BOD_5, COD, TSS, FCB and Pb, Cd and Cr.

1.4 Outline of the Report

Chapter 1 gives the introduction of the research; chapter 2 contains the literature review in which theoretical background of the various frameworks within this study is detailed. Chapter 3 consists of a description of the methods and materials used during the research. Chapter 4 discusses the results of the research and Chapter 5 gives the conclusions and recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Wastewater is generated everywhere in Malawi in both rural and urban areas. It is any water whose quality has been adversely affected by anthropogenic influence. It contains a wide range of potential contaminants in various levels of concentrations. Wastewater generally comprises of a mixture of domestic wastes from baths, sinks, washing machines, toilets and from industry. It will also contain rainwater run-off (storm water) from roads, roofs and other impermeable surfaces during the rainy season.

It is defined as a combination of domestic effluent consisting of black water (excreta, urine and faecal sludge) and grey water (kitchen and bathing wastewater); water from commercial establishments and institutions, including hospitals; industrial effluent, storm water and other urban run-off; agricultural, horticultural and aquaculture effluent, either dissolved or as suspended matter" (UN-Water, 2015). The term 'wastewater' encompasses domestic, commercial, industrial, agricultural components and faecal sludge (UN-Water, 2015).

Proper wastewater collection, treatment, discharge and disposal of accumulated sludge permits clean water to flow back to the natural environment. This assists in maintaining river flows, which is vital for many uses downstream such as abstraction, biodiversity and fisheries. Untreated wastewater pollutes the environment and creates problems for public health, water resources, wildlife and ecosystems in general. Poor disposal practices can result in high coliform counts, eutrophication in surface water bodies and fish kills (Paerl, 1997). Due to an increase in volume of wastewater generation as a result of growth in population, industrialization and the inability of Government to secure expansion of the sanitary sewerage system, sewage continues to find its way into surface water bodies like rivers, dams and lakes without any treatment (CEP Technical Report:88, 2015). For instance, in Blantyre City during the rainy season insufficient drainage has resulted in standing pools of contaminated water in Townships like Mbayani, Ndirande, Chilobwe, Bangwe, Machinjiri, Chilomoni and Chigumula (Observations by author as Blantyre City resident). These pools are a hazard to outbreaks of diseases and illnesses such as hookworm, cholera and dysentery.

2.2 Characterisation of Wastewater

Mara (2003) defines domestic wastewater as water that has been used by a community and contains all materials added to it during use. It is composed of human body wastes (faeces and urine) together with used water from personal washing, laundry, food preparation and cleaning of kitchen utensils. When it is fresh, it is grey turbid liquid with earthy but inoffensive odour. It has floating and suspended solids such as faeces, rags, plastic containers, maize cobs; smaller suspended solids such as partially disintegrated faeces, paper, vegetable peels and very small solids in colloidal i.e. non – settleable suspension as well as pollutants in solution form. When fresh wastewater loses its content of dissolved oxygen, it becomes stale or septic. Septic wastewater has an offensive odour usually of hydrogen sulphide.

Domestic wastewater consists of 99.9% water and 0.1% solids. The solids part contains 70% organic matter and 30% inorganic matter (Mara, 2003). The organic fraction is composed of proteins, carbohydrates and fats (Fig. 2.1). Carbohydrates and proteins are an excellent diet for bacteria, and engineers exploit this strong appetite for food in designing microbiological wastewater treatment infrastructure.

Sullage consists of a wide variety of chemicals; detergents, soaps, fats, greases of various kinds, pesticides and anything that goes down the kitchen sink and many more such that it is impossible to list them all. It is for this reason that wastewater treatment engineers use special parameters to characterize wastewaters.

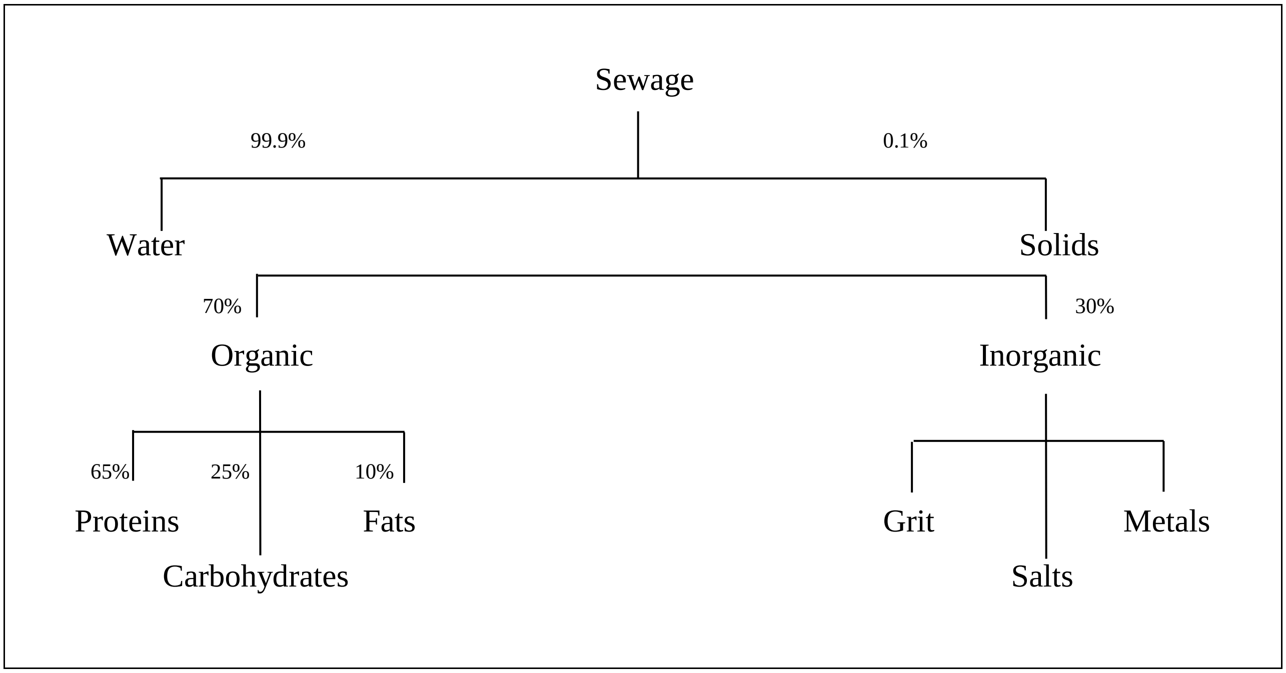

Figure 2.1: Composition of Domestic Wastewater

(Mara, D. (2003). *Domestic wastewater treatment in developing countries*. London: Earthscan.)

Wastewater is usually treated by supplying it with oxygen so that bacteria can utilize wastewater contents as food. The general equation for wastewater treatment is given in equation 1:

$$\text{Wastewater} + \text{Oxygen} \xrightarrow{\text{bacteria}} \text{Treated wastewater} + \text{new bacteria} \qquad (1)$$

Concentration of organic matter in the wastewater can easily be expressed in terms of the amount of oxygen required for its oxidation thus, oxygen demand. There are three ways of expressing oxygen demand of wastewater and are as follows:

2.2.1 Theoretical Oxygen Demand (ThOD)

This is the amount of oxygen required to oxidize organic fraction of the wastewater completely to carbon dioxide and water. The total equation for total oxidation of glucose for instance is given in equation labeled 2:

$$C_6H_{12}O_6 + 6O_6 \longrightarrow 6CO_2 + 6H_2O \qquad (2)$$

Due to complex nature of wastewater, ThOD cannot be calculated, but is approximated by the COD.

2.2.2 Chemical Oxygen Demand (COD)

This is obtained by oxidizing wastewater with a boiling acid dichromate solution. This process oxidizes almost all organic compounds to carbon dioxide and water. The reaction usually proceeds to more than 95% completion. The advantage of this measurement method is that results are obtained quickly (within 3 hours). The results do not give any information about the proportion of the wastewater that can be oxidized by bacteria and rate of bio-oxidation (Mara, 2003).

2.2.3 Biochemical Oxygen Demand (BOD)

This is the amount of oxygen required for the oxidation of wastewater by bacteria. It is therefore a measure of concentration of organic matter in a waste that can be oxidized by bacteria (bio-oxidized or biodegraded). BOD is usually expressed on a 5-day, 20°C basis that is the amount of oxygen consumed during oxidation of the wastewater for 5 days at 20°C. 5-day BOD (BOD_5) is more easily measured (Mara, 2003).

2.3 Wastewater Strength

BOD_5 or COD often measures wastewater strength. The strength of wastewater from a community is governed by its water consumption behaviour. For instance, in the United States of America (USA) where water consumption per capita is high (350 – 400 l/person day) the wastewater strength is weak (BOD_5 = 200 – 250 mg/l) whereas in the tropical countries wastewater is strong (BOD_5 = 300 – 700 mg/l). In addition to the above, wastewater strength is also affected by the amount of BOD_5 produced per person per day and this varies from country to country. It is however estimated that 40 g BOD_5 per person per day is the average amount produced in developing countries, which is used in designing of WWTPs. Table 2.1 classifies BOD and COD strength.

Table 2.1: Wastewater Strength in terms of BOD_5 and COD

Strength	BOD_5 (mg/l)	COD (mg/l)
Weak	<200	<400
Medium	350	700
Strong	500	1000
Very strong	>750	>1500

(Mara, D. 2003: Domestic Wastewater Treatment in Developing Countries. Earthscan. London)

2.4 Wastewater Collection

Domestic wastewater is collected in underground pipes called sewers to the wastewater treatment plant or septic tank for treatment and disposal. Some wastewater is collected in storm water drains. The flow is mostly by gravity. Untreated wastewater damages the environment and human health. Wastewater treatment helps to reduce transmission of excreta-related diseases, reduce water pollution and the subsequent damage to aquatic biota.

In developing countries, a small proportion of the wastewater generated by sewered communities is treated. In Latin America, for example, less than 15% of the wastewater collected in sewered cities and towns is treated prior to discharge (Pan American Health Organisation, 2000). Currently, the global burden of excreta-related disease is extremely high. Over half of the world's rivers, lakes and coastal waters are seriously polluted by untreated domestic, industrial and agricultural wastewaters (Beach, 2001; Mara, 2003; United Nations Environment Programme, 2002), and they contain high numbers of faecal bacteria.

2.5 Excreta–related Diseases

The main reason for treating wastewater is to reduce the numbers of excreted pathogens to levels where the risks of further environmental transmission of diseases they cause are reduced. Therefore, wastewater treatment plant designers need to have a good understanding of excreta – related diseases, the pathogens that cause them and how to remove them (Feachem et al., 1983). Table 2.2 below gives an overview of environmental classification of excreta – related diseases. It is noted from the table that the first five are excreted infections, which are contagious through excreta infections. The last two categories in the table are vector–borne excreta–related diseases which are spread by inspects and rodents.

Table 2.2: Environmental Classification of Excreta-Related Diseases

ID	Category	Environmental transmission features	Major example of infections	Environmental transmission focus
a)	*Non-bacterial faeco-oral diseases*	Non-latent Low to medium persistence Unable to multiply High infectivity No immediate host	Viral: Hepatitis A and E Rotavirus diarrhea Norovirus diarrhea Protozoan: Amoebiosis Cryptosporidiosis Giardiasis Helminthic: Hymenolepiasis	Personal domestic wastewater
b)	*Bacterial faeco-oral diseases*	Non-latent Medium to low persistence Able to multiply Medium to low infectivity No intermediate host	Campylobacteriosis Cholera Pathogenic Escherichia coli infection Salmonellosis Shigellosis Typhoid Yesiniosis	Personal domestic wastewater Crops
c)	*Geohelminthiases*	Latent Very persistent Unable to multiply Very high infectivity No intermediate host	Ascariasis Hookworm infection Strongyloidiasis Trichurasis	Peri-domestic wastewater Crops
d)	*Taeniases*	Latent Persistent Able to multiply Very high infectivity Cow or pig intermediate host	Taeniasis	Peri-domestic wastewater Fodder crops
e)	*Water-based helminthiases*	Latent Persistent Able to multiply High infectivity	Schistosomiasis Clonorchiasis Fasciolopsiasis	Wastewater Fish Acquatic species or acquatic vegetables

		Intermediate acguatic host (s)		
f)	*Excreta-related insect-vector disease*		Bancroftian filariasis transmitted by Culex quinquefasciatus	Wastewater
g)	*Excreta-related rodent-vector disease*		Leptospirosis	Wastewater

(Mara, D. 2003*: Domestic Wastewater Treatment in Developing Countries.* Earthscan. London)

2.6 Wastewater Treatment Status in Malawi

Wastewater treatment services are available in the cities only, namely, Mzuzu, Lilongwe, Zomba and Blantyre. In Mzuzu, the wastewater treatment plant is located at Moyale, in Lilongwe it is at Kauma; in Zomba they are located at Chancellor College and Chikanda, and in Blantyre the wastewater treatment plants are Soche WWTP located at Zingwangwa, Blantyre WWTP located at Manyowe, Chirimba WWTP in Chirimba and Limbe WWTP in Limbe. These are offsite sewerage systems and are operated by City Councils (Mzuzu, Lilongwe, Blantyre and Zomba City Councils). About 15% of the population is connected to the sewerage network (National Environmental Action Plan, 1994), and that wastewater from 85% of the population is either treated through decentralized wastewater treatment systems (DEWATS) like septic tanks and latrines or discharged directly into surface water bodies like rivers and dams untreated. This is likely contaminating surface and ground water sources. Water users downstream are at a big risk of catching water-borne diseases such as cholera as the untreated wastewater contains very high concentration of pathogens.

Lundgen (2012) in her study to evaluate efficiency of two wastewater treatment plants in Zomba (situated at Chancellor College and Chikanda) noted that both plants were inefficient. Effluent from these plants contained elevated levels of chemical compounds at discharge points into the rivers. She discovered that poor maintenance of these wastewater treatment plants (WWTPs) was the major reason for their dwindling performance. This argument supports what Agrifor Consult

(2006) had established that letting of inadequately treated sewage from treatment works is mainly due to system break downs, sewer line blockages due to poor maintenance, improper design of some sections and lack of public awareness on use of the sewerage systems. These factors among others let wastewater flow into surface water bodies partially treated or untreated at all thereby contaminating the water. Lack of adequate wastewater treatment causes severe water pollution and outbreaks of water-borne diseases especially in traditional housing areas (THAs) and squatters in urban areas (Kaonga, et al., 2013).

WWTPs in the city of Blantyre are very limited in capacity to treat all wastewater released per day. Besides this, the systems were inherited from the colonialists having been designed in the 1950s to cater for a much smaller population, for instance, the design values for Soche, Blantyre and Limbe WWTPs are 4,100 m^3/day, 2,400 m^3/day and 630 m^3/day respectively. The 1995 study indicated that Soche, Blantyre and Limbe WWTPs were receiving 6,240 m^3/day, 7,950 m^3/day and 2,850 m^3/day respectively (Blantyre City Council, 2018). It could be expected that in 2018 the wastewater flows to these WWTPs should be higher due to increased population and water consumption. However, the 2018 wastewater flows for Soche, Blantyre and Limbe WWTPs were 4,059 m^3/day, 4,449 m^3/day, and 0 m^3/day respectively. Limbe WWTP is not functional. Inlet pipe was vandalized and requires rehabilitation. Looking at wastewater flows of 1995 it is evident that the treatment plants were being overloaded and required expansion for them to accommodate the flows. The overloading of the sewerage system has resulted in not only poor effluent quality but also frequent blockage of sewage pipes resulting into spillage of sewage in townships, roads and rivers. The heavy pollution of streams due to malfunctioning of the sewerage system has resulted in odour production from decomposed waste and stagnant water, breeding of mosquitoes and other disease vectors, loss of aquatic life and poor general outlook of the city.

Other studies on a similar issue revealed that quality of effluent discharged by the four major WWTPs in the City of Blantyre (Limbe, Soche, Blantyre and Chirimba) was also below required standards. Effluent from these WWTPs contain higher levels of chemical, physical and biological compounds than recommended by MBS and WHO (Chipofya, 2010; Kuyeli, 2007; Mtethiwa et al., 2008) (Tables 2.3 and 2.4 for Soche Wastewater Treatment Works). This effluent is discharged into rivers without considering the safety of water users downstream. For instance, Soche WWTP discharges effluent into Mlambalala whose flows join Naperi River, Blantyre WWTP discharges into Mudi River, Limbe WWTP discharges effluent into Chimwankhunda and Limbe Rivers; and Chirimba WWTP discharges into Ngumbe and Likhubula Rivers (Blantyre City Council, 2018).

Table 2.3: Soche WWTP Influent and Effluent Physico-chemical Characteristics for the Dry Season in mg/l

Parameter	BOD_5	COD	TSS
Influent	490±9.8	883±12.5	157±2.32
Effluent	25±0.6	353±4.31	102±5.6
Efficiency (%)	95	60	35
Malawi Standard	20	60	30
WHO Guidelines	20	60	30

(Chipofya, V.K. (2010). Comparison of pollutant levels in effluent wastewater treatment plants in Blantyre, Malawi. *International Journal of Water Resources and Environmental Engineering, 2(4), 79-86*)

Table 2.4: Soche WWTP Influent and Effluent Physicochemical Characteristics for the Wet Season in mg/l

Parameter	BOD_5	COD	TSS
Influent	760±0.0	907±10.05	40±0.0
Effluent	34±2.69	735±16.35	8±0.02
Efficiency (%)	96	19	80
Malawi Standard	20	60	30
WHO Guidelines	20	60	30

(Source: Chipofya, V.K. (2010). Comparison of pollutant levels in effluent wastewater treatment plants in Blantyre, Malawi. *International Journal of Water Resources and Environmental Engineering, 2(4), 79-86*)

Chipofya (2010) argues that limited or non-existent industrial effluent pre-treatment has also contributed to the severe water quality degradation in the city of Blantyre and the situation poses a threat to the water users downstream. This situation underscores the need for wastewater

treatment. However, the author (Chipofya, 2010) did not determine the level of water contamination in the analyses to justify his claim of severe water quality degradation. Wastewater Treatment Plants (WWTPs) receive municipal sewage, which is comprised of domestic and industrial effluents where the typical wastewater parameters are BOD_5, COD and TSS. The treatment target at both plants is BOD_5, COD, and TSS reduction (Chipofya, 2010).
Surface water from streams is used by local residents for washing clothes, bathing and irrigating crops, which may be eaten raw, and in some cases, the streams are used as a source of drinking water (Lakudzala et al., 1999; Mkandawire et al., 2008; Sajidu et al., 2007). There is no information about the quantities of wastewater generated per day. In addition, the magnitude of surface water contamination by sewage is little known.

2.7 Why Wastewater Treatment

Untreated wastewater causes major damage to the environment and to human health. Therefore, wastewater should always be treated before being discharged to the environment in order to reduce transmission of excreta–related diseases and also reducing water pollution and the subsequent damage to aquatic biota.

In developing countries (including Malawi), only a small proportion of the wastewater produced by communities, which are connected to the sewerage network is treated. In Latin America for instance, less than 15% of the wastewater collected in sewered cities and towns is treated prior to discharge (Mara, 2003; Pan American Health Organisation, 2000). This has led to pollution of over half of the world's rivers, lakes and coastal waters by untreated domestic, industrial and agricultural wastewaters (Beach, 2001; United Nations Environment Programme, 2002), and they contain high numbers of faecal bacteria (Ceballos et al, 2003).

2.8 Wastewater Treatment and Technologies

Wastewater treatment aims at reducing the concentration of pollutants to levels where the risks of further transmission of the diseases they cause is substantially decreased. The process goes through three major stages called physical, biological and chemical processes. Below are the stages:

2.8.1 Physical Process

This is the first stage of wastewater treatment. It involves the removal of large floating objects, for instance; rags, maize cobs, pieces of wood; and heavy mineral particles, e.g. sand and grit. This is done to prevent floating material from accumulating on the surface of wastewater stabilization pond and heavy solids entering the pond sludge layer; hence, protect from damaging the equipment used in the subsequent stages of treatment (e.g. floating aerators in aerated lagoons or any pumps which may be used). This pre-liminary treatment comprises of screening and grit removal.

2.8.1.1 Screening

Closely spaced mild steel bars, 15 – 25mm apart, are placed across wastewater flow channel to remove coarse solids in the wastewater by trapping them. Flow velocity through the screen is as low as below one meters per second (v <1 m/s). The screens are usually inclined at 60 degrees to the horizontal. The screenings are raked manually for small treatment works or mechanically for large treatment works with wastewater flows greater than 1000 m^3/day. Disposal of the screenings is achieved by burying (for small treatment plants) or dewatering in a hydraulic press and then buried or incinerated on site or landfill (Mara, 2003).

2.8.1.2 Grit Removal

Heavy inorganic fraction of the wastewater solids is called grit. It includes grit, sand, eggshells, ashes, charcoal, glass and pieces of metal. It may also contain some heavy organic matter such as seeds and cone grounds. It has an average relative density of approximately 2.5 (Mara, 2003) and hence has a much higher settling velocity (about 30 mm/s) than organic solids (about 3 mm/s). The difference in sedimentation rates is exploited in grit removal plants where for ease of handling and disposal, the organic fraction must be kept to a minimum (<15%).There are two basic types of grit removal techniques. These are constant velocity channels and grit tanks or traps (Mara, 2003).

2.8.1.3 Constant Velocity Grit Channels

Grit particles in a slow flowing wastewater with velocity of about 0.3 m/s, settle out but organic solids do not. Constant low flow velocity is maintained by a standing wave flume (Venturi or Parshall) located immediately downstream of a grit channel (a parabolic cross section channel is ideal to maintain constant flow speed through the channel).

2.8.1.4 Grit Traps

According to Mara (2003), grit traps are economically viable where wastewater flows are higher than 5,000 m^3/day. The same was alluded by Jones and Attwood (2002).

2.8.2 Biological Process

Microorganisms treat wastewater biologically. The process is done either anaerobically or aerobically. Anaerobic processes take place in the absence of exygen whereas aerobic processes take place in presence of oxygen. These processes take place in series (Gijzen, 2002; Mara, 2003) not only in waste stabilization ponds but also in other systems such as activated process and attached growth systems in conventional wastewater treatment.

Waste stabilization ponds are comprised of anaerobic, facultative and maturation ponds. Anaerobic and facultative ponds are designed for BOD removal whereas maturation ponds are designed for faecal bacteria removal (some removal of faecal bacteria occurs in anaerobic and facultative ponds where most of the removal of helminth eggs takes place, likewise some removal of BOD also occurs in maturation ponds where most of the removal of nitrogen, N, and phosphorous, P, takes place (Mara, 2003)).

Facultative and maturation ponds are photosynthetic ponds because oxygen needed by pond bacteria to oxidise wastewater BOD is supplied by micro-algae that grow naturally and profusely in these ponds. Pond bacteria mainly provide carbon dioxide needed by algae for photosynthesis as a byproduct of their metabolism. There is a mutualistic relationship between pond algae and pond bacteria. In addition to this, the algae are also important for creating conditions within the ponds for faecal bacteria die – off.

The Waste Stabilization Ponds (WSP) types given above are arranged in series; first an anaerobic pond, second a facultative pond and lastly one or more maturation ponds (where necessary to achieve the required effluent quality). There may be more than one series of WSP at any one site, each receiving an equal proportion of wastewater flow. Effluent from a series of ponds is of better quality than a single pond of the same size because the overall performance of a series of ponds approximates that of a plug flow reactor (Mara, 2003).

2.8.2.1 Anaerobic Ponds

Anaerobic ponds are the first type of pond used in a series of ponds. They are 2 – 5 m deep and receive high organic loading (usually over 100 g BOD/m^3 day, equivalent to 3,000 kg/ha day for a depth of 3 m) that they contain no dissolved oxygen and no algae, though a thin film of chlamydomonas may be present at the surface. They function like open septic tanks and their primary function is BOD removal.

2.8.2.2 Facultative Ponds

There are two types of facultative ponds namely: primary and secondary facultative ponds. The primary facultative ponds receive raw wastewater after preliminary treatment and secondary facultative ponds receive settled wastewater (usually effluent from anaerobic ponds). Facultative ponds are designed for BOD removal on the basis of low surface BOD loading in the range 100 – 400 kg/ha day.

2.8.2.3 Maturation Ponds

The main function of maturation ponds is to reduce number of excreted pathogens, mainly faecal bacteria and viruses, present in the effluent of facultative ponds to a level suitable for agriculture or agricultural re-use. BOD, suspended solids and nutrients like nitrogen and phosphorous are removed at a very slow rate.

2.8.3 Chemical Process

This process involves addition of chemicals to the wastewater to enhance sedimentation of settle-able particles and killing of pathogens before discharging effluent to the environment.

Although primary and secondary treatment operations are efficient in removing most wastewater pollutants, some pollutants require special forms of treatment for their removal. Phosphorous is one such pollutant of special concern. If untreated, phosphorus in the final effluent of a wastewater treatment plant may have a negative impact on receiving waters. Phosphorous is one of the major nutrients associated with the growth of aquatic plants. Sources of phosphorous include; human waste, detergents containing phosphate additives and corrosion control chemicals used in water supplies and industrial discharges. High concentrations of phosphorous in receiving waters promote excessive growth of algae and aquatic plants which may disrupt the natural ecological balance of the receiving water. Rapid deterioration of water quality could result in acceleration of the eutrophication process of the receiving body of the water (City of Guelph, n.d.).

Phosphorus removal methods may be characterized as being either biological or chemical precipitation techniques. The present practice is the use of a metal salt which reacts with soluble phosphorous to form an insoluble precipitate. This precipitate settles with the sludge during settling operations and is thus removed from the wastewater. The most common metal salt in use is ferrous chloride, also known as “pickled liquor”. Application points for iron solutions are typically immediately upstream of the primary settling tanks, at the influent end of the aeration tanks, or at both points simultaneously. It is important that chemicals used for phosphorous precipitation be intimately mixed with the wastewater to ensure uniform dispersion to achieve maximum removal efficiencies.

Another essential chemical treatment practiced at wastewater treatment facilities involves disinfection of the final effluent. Disease causing or pathogenic microorganisms are potentially present in all wastewaters due to human discharges. These microorganisms must be removed or killed before treated wastewater is discharged to receiving waters. Chlorination for disinfection purposes results in the destruction of essentially all of the pathogenic microorganisms and thus prevents the spread of waterborne diseases. Sodium bisulphate is added following disinfection to dechlorinate the wastewater effluent prior to discharge (City of Guelph, n.d.).

2.9 Population in Blantyre City

One of the specific objectives of this study is to determine volume of wastewater released per land use category in Blantyre City. As such, population estimate of Blantyre City is very useful for successful execution of this objective.

2.9.1 Population Estimates

The current population of the city of Blantyre is estimated at 1,075,636, up from 729,706 in 2008 (Tables 5 - 7). The success and accuracy of the calculated total volume of wastewater released in Blantyre City is largely dependent on the ability to forecast future population growth accurately. The figures need to be reviewed regularly and checked against any new population data that becomes available over the period up to 2020 (Blantyre Urban Structure Plan, 2000).

2.9.2 Assumptions

The demographic model utilised for the projection of the Blantyre population was the “Cohort-Component Method for Projections” which is based on the following input variables:

a) A current Total Fertility Rate (TFR) of 5.4, which declines over the period under review.

b) An average length of stay in Blantyre of 13.9 years as indicator of migration trends.

c) Variable urbanisation/migration trends.

d) A current age distribution profile sourced from the Blantyre Structure Plan Background Study Report.

e) A life expectancy at birth of 48 years and variable rates for AIDS and Infant Mortality Rates (IMR), which are applied to the model life tables to determine prevalent mortality.

2.10 Scenarios

Two scenarios were generated from the model. These scenarios are as follows:

2.10.1 High Growth Scenario

a) Migration into Blantyre City remains relatively high
b) The TFR rate falls to 3.6 by the year 2020
c) The prevalence of AIDS in the local population decreases over time

2.10.2 Low Growth Scenario

a) Migration into Blantyre City steadily decreases over time
b) The TFR rate falls to 2.9% by the year 2020.
c) The prevalence of AIDS in the local population increases over time

2.11 Blantyre City Annual Projected Population Estimates

The population projections generated by the model are presented in Tables 2.5 and 2.6 as follows:

Table 2.5: Projected Population using two different scenarios

	Projected Population			
Year	**1999**	**2005**	**2010**	**2015**
Scenario 1	519 033	641 864	794 850	967 355
Scenario 2	519 033	641 840	784 317	926 436

Population projections for intermediate years not shown in the above table can be made through simple extrapolation of the data by utilising the following growth rates:

Table 2.6: Projected Annual Growth Rates.

Period	1999-2005	2006-2010	2011-2015	2016-2020
Scenario 1	3.60 %	4.37 %	4.01 %	3.6%
Scenario 2	3.60 %	4.09 %	3.39 %	2.8%

The results of this analysis yield the population profile shown in Table 2.7 below:

Table 2.7: Projected Population: 2000 – 2020

Year	Scenario 1	Scenario 2
1999	519,033	519,033
2000	537,737	537,733
2001	557,114	557,107
2002	577,190	577,180
2003	597,989	597,975
2004	619,538	619,519
2005	641,864	641,840
2006	669,902	668,098
2007	699,165	695,429
2008	729,706	723,879
2009	761,582	753,492
2010	794,850	784,317
2011	826,695	810,880
2012	859,816	838,342
2013	894,264	866,734
2014	930,092	896,088
2015	967,355	926,436
2016	1,002,180	952,376
2017	1,038,258	979,042
2018	1,075,636	1,006,455
2019	1,114,358	1,034,636
2020	1,154,475	1,063,607

(Source: Blantyre Urban Structure Plan. (2000). Blantyre: Blantyre City Council)

Note:

The population figures for the intermediate years as illustrated above, are based on the extrapolation of data utilising single growth rates (as opposed to data generated directly by the model) and therefore do not carry the same high degree of accuracy as the population figures provided for the five-year intervals. For the purpose of calculating future needs, it is prudent to use the higher figure, especially since census figures normally represent an undercount of the population (Blantyre Urban Structure Plan, 2000).

CHAPTER 3: MATERIALS AND METHODS

3.1 Introduction

This section presents materials and methods that were used in the study.

3.2 Research Design

Survey and laboratory experiment research strategies with quantitative design approach were used in this study. The focus was to get quantifiable data that would be analysed using Statistical Package for Social Scientists (SPSS) and Excel Spread Sheet.

3.3 Study Area

The study was conducted within Blantyre City boundary. The survey was carried out in twenty areas. The areas were sampled using purposive sampling technique. The sampled areas are presented in Table 3.1:

Table 3.1: Study Areas in Blantyre City

Id	Low density areas	Medium density areas	High density areas	Traditional housing areas (THAs)	Industrial Areas
a)	Nyambadwe	Chinyonga	Mbayani	Ndirande Goliyo	Makata
b)	Namiwawa	Soche East	Nkolokoti	Chilomoni Mthukwa	Ginnery Corner
c)	Sunnyside	Namiyango	Nancholi	Manje	Chirimba
d)	BCA	Manja	Misesa	Chilobwe	Maselema

Laboratory tests[2] were done on twenty-eight (28) water samples collected from Mudi, Naperi, Limbe and Chirimba rivers on two points; before and after effluent discharge from Blantyre, Soche, Limbe and Chirimba Wastewater Treatment Plants respectively.

3.4 Survey

A baseline survey using questionnaires on randomly selected participants was administered in selected areas to determine how wastewater is managed and estimate volume of wastewater released per land use in Blantyre City with focus on industrial, institutional, residential (low density, medium density, high density, THAs). Figure 3.1 shows the author administering a research protocol with a respondent at Manje Township in Blantyre City.

3.4.1 Sample Size

The main purpose of sampling is to produce a representative sample that has characteristics similar to the population (Raddon, 2015). Calculation of the sample size was adopted with ±8 % desired level of precision, 92% confidence level and 0.5 degree of variability (Ncube, 2011). Taro Yamane's formula, labelled equation 3 below, was used to calculate a sample size that would represent the population of Blantyre City because it is applicable where the population is finite and its size is known (www.quora.com/what-is-Yamane-sample-calculation accessed on 05/09/2019).

Sample size (number of questionnaires), $$n = \frac{N}{1+N(e)^2} \quad (3)$$

Where N = population size, n = sample size, e =desired level of precision

Based on the population (N) of 1,075,636 people for Blantyre City (Projected based on NSO, 2008 census) and ±8% level of precision and computing from the above formula, a sample size of n = 156 respondents representing 156 questionnaires was determined as a minimum.

[2] Laboratory tests for Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total coliform and Faecal Coliform Bacteria (FCB) and heavy metals like Lead (Pb), Cadmium (Cd) and Chromium (Cr)

3.4.2 Data Processing and Analysis

The data from questionnaires were captured and analysed using the Statistical Packaging for Social Sciences (SPSS Version 20.0). The outputs from SPSSv20.0 were presented in form of tables and graphs.

Figure 3.1: Researcher Conducting Field Survey
Author, George Chidulo, conducting field survey in Manje in the city of Blantyre on 30 June 2018

3.5 Water Quality Experiments

3.5.1 Sample Size

Blantyre City has four WWTPs which discharge effluent into four rivers as well. Since the population is small (only four rivers) all four rivers were sampled. The rivers are Mudi, Naperi, Limbe and Chirimba, which receive effluent from Blantyre, Soche, Limbe and Chirimba WWTPs respectively.

3.5.2 Sample Collection

Water samples from the upstream and downstream of a wastewater treatment plant were collected by grab method from Mudi, Naperi, Limbe and Chirimba Rivers. The water samples, twenty eight (28) in total were collected before the onset of the rains on 17th November 2018 from 10 am to 5:30 pm, once at each point. The day was cloudy. Each sample was immediately kept in a cooler box after collection to preserve life of probable microorganisms. The samples were taken to the laboratory on the same day where they were kept in a refrigerator. Laboratory tests ran from Monday, 19th November, 2018 to 23rd November, 2018 for wastewater pollutants namely BOD_5, COD, TSS and hard meals namely Pb, Cr and Cadmium Cd.

Four[3] water samples were collected from a selected point on each of the four rivers upstream of a wastewater treatment plant. A total of 16 samples were collected from Limbe, Naperi, Mudi and Chirimba rivers before effluent is discharged. The specific sampling points were as follows: Sampling point on Mudi River was near Hotel Victoria on coordinates 0717000, 8251299 before Blantyre WWTP. The second one on Naperi River was near Joy Radio Station on coordinates 0714708, 8251309 before Soche WWTP. The third one on Limbe River was on coordinates 079748, 8247444, in Chiwembe, before Limbe WWTP. Lastly, the fourth point on Chirimba River was on coordinates 0717773, 8257927, before Chirimba WWTP.

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[3] Four samples per point was determined as economically sensible number to spread margin of error away amidst limited financial resources.

Four (4) water samples, determined by purposive non-random sampling technique, were collected from a point where effluent is discharged into each of the three rivers downstream of a wastewater water treatment plant except Chirimba River (Chirimba WWTP was vandalized hence not operational, therefore samples were not collected downstream). A total of 12 samples were collected from Mudi, Naperi and Limbe rivers after effluent is discharged. The sampling points were as follows: on Mudi River at Manyowe on coordinates 0713010, 8251173 after Blantyre WWTP whereas on Naperi River it was near Stella Maris on coordinates 0714097, 8249138 after Soche WWTP and on Limbe River sample were collected near Namame Primary School in Manje on coordinates 0719165, 8246015 after Limbe WWTP. Figure 3.2 below is a map showing sampling points. Twenty-eight (28) samples were collected in all. Temperature (T) and Power of Hydrogen (pH) were tested on site for each sample before storage in a cooler box immediately after collection in order to preserve life of probable microorganisms in the water samples while in transit to the laboratory (MS 2015).

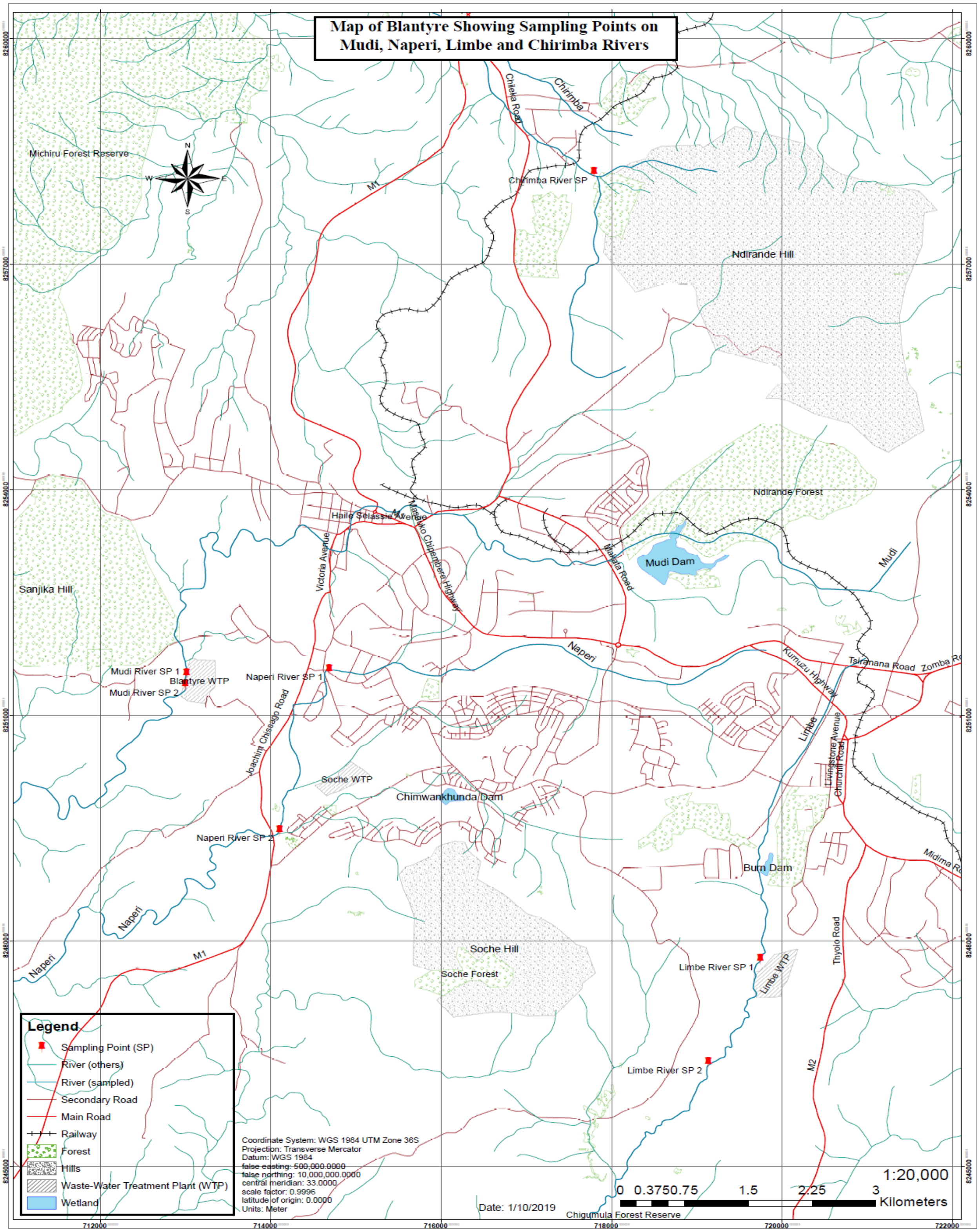

Figure 2.2: Map of Blantyre City showing sampling points on Mudi, Naperi, Limbe and Chirimba Rivers (produced by author)

3.5.3 Sample Tests

Laboratory tests on the samples were undertaken in accordance with American Public Health Association (APHA) (2005) methods. Below is a detailed presentation of how specified parameters were tested:

3.5.3.1 Determination of BOD_5

An aliquot sample (20 ml) was put into a sample flask to which distilled water was mixed with 2.0 ml each of phosphate buffer, magnesium sulphate, and calcium chloride and ferric chloride solutions for each litre of dilution water. After diluting and mixing well and allowing no air in the sample to avoid getting false results, it was then pipetted into two BOD bottles, one for incubation for 5 days at 20 ^{0}C and the other one for the determination of initial dissolved oxygen. An aliquot of sample (20 ml) was placed in a sample flask to which distilled water was added and 2.0 ml each of phosphate buffer, magnesium sulphate, calcium chloride and ferric chloride solutions for each litre of dilution water. After diluting and mixing well and allowing no air in the sample, it was then pipetted into two BOD bottles, one for incubation for 5 days at 20 ^{0}C and the other one for the determination of initial dissolved Oxygen. During the determination of dissolved oxygen levels, a stopper was carefully removed from a reagent bottle containing a sample and 2 mL of MnSO4. H_2O solution (182 g in 500 mL of deionised water) was added. Then, 2 mL of alkali-azide-sodium iodide solution (5g NaN3, 250 g NaOH and 70 g NaI in 500 mL of deionised water) was pipetted into the reagent bottle by lowering the tip of the pipette below the surface of the sample. The stopper was then replaced onto the bottle and inverting the bottle at least 5 times to mix the contents. After allowing the developed precipitate to settle, 2 mL of concentrated sulphuric acid was added to the mixture in the reagent bottle. The stopper was then replaced and the reagent bottle was shaken until all the precipitate was dissolved. Finally, the sample aliquot was pipetted into a 250 mL Erlenmeyer flask before titrating with standardized 0.025 M sodium thiosulphate solution. The difference in the amount of dissolved oxygen between the incubated samples and the non-incubated ones was used to calculate BOD values (Kuyeli, 2007).

3.5.3.2 Determination of Chemical Oxygen Demand (COD)

About 20 ml of the homogenized sample in the reflux condenser was added to a 10 ml aliquot of standard potassium dichromate (0.02M) containing mercuric sulphate and 30 ml of sulphuric acid containing silver sulphate. The mixture was heated for 2 hours in the range of 148 and 150 ^{o}C and then cooled to room temperature. The condenser was washed by distilled water and the final mixture was used to make 100 ml solution which was titrated against 0.12M ammonium iron (II) sulphate using Ferron indicator. To calculate COD levels, equation 4 below was used:

$$COD = \frac{8000(b-s)n}{Sample(ml)} \quad (4)$$

Where **b** is the volume of FAS used in the blank sample,

s is the volume of FAS in the original sample, and

n is the normality of FAS.

3.5.3.3 Determination of TSS

Total Suspended Solids (TSS) were determined using pre-weighed glass filters (Chipofya, 2010). Exactly 10ml of a sample was filtered through a pre-weighed glass fibre filter placed on a vacuum pump. Three successive 10 ml volumes of distilled water were used to rinse the sample on the filter to allow complete drainage. Suctioning continued until the filtration was complete (APHA, 1985). Afterwards the filter was removed from the vacuum pump to a stainless planchet as a support. The filter was then dried at least for one hour in an oven, and then cooled in a desiccator to balance temperature and then weighed on analytical balance. The calculation of the total suspended solids (TSS) was done as in equation 5 below:

$$TSS\ (mg/l) = \frac{(A-B)x1000}{Sample(ml)} \quad (5)$$

Where:

A = Weight of filter + dried residue in milligrams (mg)

B = Weight of the filter in milligrams (mg)

3.5.3.4 Determination of Coliform Bacteria (Total and Faecal).

Total coliform and faecal coliform bacteria were determined by membrane filtration method from APHA (Kaonga, et al., 2013).

Non-potable water samples were diluted so that the bacteria that grows on the filter is at a density that can be measured. A sample size that gives 20 to 200 colony-forming units (CFU) per filter was selected. The ideal sample volume for non-potable water or wastewater yields 20–80 coliform colonies per filter. The dilution-sterilized water helped to distribute the bacteria uniformly across the membrane filter (Hach Company, 2012).

The sample was filtered through a membrane filter of pore size 0.22 – 0.45 µm and thickness 150 µm, which retains the bacteria. The filter was put in a petri dish on an absorbent pad that contained a nutritional broth that is selective for the growth of a specific organism. The petri dish containing the filter and pad was incubated for 24 hours at 37^{o}C for total coliforms and 44^{o}C for faecal coliforms. After incubation, the colonies that had grown were identified and counted as for equation 6 below for a single filter test:

$$\text{Bacterial colonies per 100 ml (Cfu/100 ml)} = \frac{\text{Bacterial colonies counted x 100}}{\text{ml of sample}} \qquad (6)$$

3.5.3.5 Determination of Lead

Lead was determined by using a Buck Scientific model no. 200A atomic absorption spectrophotometer in accordance with APHA guidelines. A stock solution corresponding to 1000 mg/l of Lead for testing was prepared as follows:

Approximately 1.0 g Lead metal of minimum purity 99.5 % was weighed and diluted in a covered 250ml glass beaker with 10 ml of nitric acid (HNO_3). 100ml of water was then added. The solution was boiled to expel nitrous fumes, cooled and then transferred to 1000 ml volumetric flask and fill to the mark with water. Then, a standard solution corresponding to 10 mg/l of Pb was made by pipetting 10.00ml of lead stock solution into a 1000 ml volumetric flask. 20ml of nitric acid was added, filled up to the mark with water and mix well (Srikanth, Somarsekhar, & Kanthi, 2013). This solution was tested by Atomic Spectrophotometer (AAS).

Atomic absorption spectrometry (AAS) is an analytical technique that measures the concentrations of elements qualitatively and quantitatively (Baul, Sara, & Srinivas, 1992). It is a spectro - analytical instrument for the quantitative determination of chemical elements employing the absorption of optical radiation (light) by free atoms in the gaseous state. When a beam of optical radiation of a particular metal (for instance; Lead, Chromium, Cadmium) passess through gaseous metal atoms, the radiation is absorbed by the specific metal atom under test present in the gaseous state and the atom is transferred from ground to higher energy state and produces a characteristic radiation, which is recorded by the detector (Nema, Maity, & Sarkar, 2012).

Metal ions in a solution are converted to gaseous atomic state by means of a flame. The technique of FAAS requires a liquid sample to be aspirated, aerosolized, and mixed with combustible gases, such as acetylene and air or acetylene and nitrous oxide. The mixture is ignited in a flame whose temperature ranges from 2100 to 2800ºC. During combustion, atoms of the element of interest in the sample are reduced to free, unexcited ground state atoms, which absorb light at characteristic wavelengths. The characteristic wavelengths are element specific and accurate to 0.01-0.1nm. To provide element specific wavelengths, a light beam from a lamp whose cathode is made of the element being determined is passed through the flame. A device such as a photon multiplier can detect the amount of reduction of the light intensity due to absorption by the analyte, and this can be directly related to the amount of the element in the sample (Nema, Maity, & Sarkar, 2012)

The presence of heavy metals in aquatic ecosystem has far-reaching implications directly to the biota and indirectly to man. They also cause irregularity in blood composition, badly effect vital organs such as kidneys and liver. Heavy metals including both essential and nonessential elements have a particular significance in ecotoxicology, since they are highly (Baul, Sara, & Srinivas, 1992).

3.5.3.6 Determination of Cadmium

Cadmium was determined by using a Buck Scientific model no. 200A atomic absorption spectrophotometer in accordance with APHA guidelines. A stock solution corresponding to 1000 mg/l of Cd for testing was prepared as follows:

Approximately 1.0 g Cadmium metal of minimum purity 99.5% was weighed and diluted in a covered 250 ml glass beaker with 10 ml of nitric acid (HNO_3). 100ml of water was added. The solution was boiled to expel nitrous fumes. It was cooled and transferred to 1000 ml volumetric flask and filled with water up to the mark (1000 ml mark). Then, a standard solution corresponding to 10 mg/l of Cd was made by pipetting 10.00 ml of Cd stock solution into a 1000 ml volumetric flask. 20ml of nitric acid was added, then fill up to the mark with water and mix well (Srikanth, Somarsekhar, & Kanthi, 2013). This solution was tested by Atomic Spectrophotometer (AAS).

3.5.3.7 Determination of Chromium

Chromium was determined by using a Buck Scientific model no. 200A atomic absorption spectrophotometer in accordance with APHA guidelines. A stock solution corresponding to 1000 mg/l of Chromium for testing was prepared as follows:

Approximately 1.0 g Chromium metal of minimum purity 99.5% was weighed and diluted in a covered 250 ml glass beaker with 10 ml of nitric acid (HNO_3). 100 ml of water was added. The solution was boiled to expel nitrous fumes, cooled and transferred to 1000 ml volumetric flask and filled to the mark with water. Then, a standard solution corresponding to 10 mg/ l of Chromium was made by pipetting 10.00 ml of stock solution into a 1000 ml volumetric flask. 20ml of nitric acid was added. Water was filled up to the mark (1000 ml mark) and mix well (Srikanth, Somarsekhar, & Kanthi, 2013). This solution was tested by Atomic Spectrophotometer (AAS) in a process as explained above.

3.5.4 Determination of General Wastewater Disposal Status

Sample size for the survey was 156 questionnaires and number of areas selected to participate in the survey were twenty (20) as alluded to above. Each area was represented by a sample size in proportion to its population (Appendix 3). Respondents were selected randomly. The questionnaire was divided into three parts namely A, B and C. Part A captured data for characterization of the respondent. Part B of the questionnaire captured data from respondents for specific objective number 1; whereas Part C of the questionnaire captured data from respondents for specific objective number two (Appendix 1). The questionnaires were personally administered as a research protocol in all selected areas. A total of 184 questionnaires were successfully completed by the end of the survey from June 2018 to August 2018.

Survey data from 184 questionnaires were captured in SPSS v 20 for analysis. A multiple response set for dichotomous variables of available wastewater disposal methods namely septic tank, sewage, storm water drains and water bodies was created and analysed based on number of respondents and number of answers for comparison of outcomes. Results were determined based on number of answers column.

3.5.5 Determination of Domestic Wastewater generated per day per residential land use category

Sample size for the survey was 156 questionnaires and number of areas selected to participate in the survey were twenty (20) as alluded to above. Each area was represented by a sample size in proportion to its population and respondents were selected randomly. The questionnaires were administered as research protocols in all selected areas and 184 questionnaires were successfully completed by the end of the survey.

Survey data from 184 questionnaires were captured in SPSS v 20 for analysis. A new variable, water consumption per capita per residential land use category, was transformed from the inputted data and was used to calculate wastewater generated per capita per land use category. This variable was then cross-tabulated with residential land use type.

Data on population and water consumption was used to calculate water consumption per capita. This new variable was used to estimate wastewater released per person per day per land use category using equation number 7. This equation is used to estimate amount of generated dry weather domestic wastewater ignoring infiltration and industrial process discharges, I and E respectively because they cannot be measured with reasonable amount of accuracy. These are depicted in equations number 8 and 9.

Generated dry weather domestic wastewater, $Q_{ww} = 10^{-3}kqP$ (7)

(Where P = population, q = water consumption per capita per day in litres/day/person, k = return factor, 0.8 – 0.9)
From survey data, average q = 92.9 l/per person/day

$$Q_{ww} = 10^{-3}kqP + I \quad (8)$$

(Where I = infiltration from underground water)

$$Q_{ww} = 10^{-3}kqP + I + E \quad (9)$$

(Where E = wastewater flow from industrial processes (Mara, 2003)
Generated dry weather domestic wastewater amounts per capita per land use were then multiplied by corresponding population size per land use category.

3.6 Parameter Selection Justification

Faecal coliforms were selected because they are biological indicators of faecal water contamination (Kaonga, et al., 2013). BOD_5, COD and TSS were selected because they are typical wastewater parameters such that their presence in the water would suggest wastewater contamination (Chipofya et al., 2010). Hard metals namely Pb, Cr and Cd were selected because they are typically traced to industrial effluents from Makata, Ginnery Corner, Chirimba and Maselema Industrial Sites in the City.

3.7 Data Processing and Analysis

The quantitative data collected through questionnaires were analysed using the Statistical Package for the Social Science (SPSS Version 20.0). The data collected through laboratory tests were captured and analysed using Excel Spreadsheet.

Correlation analysis was used to describe the strength and direction of the relationship between variables (Festinger, 2005). SPSS v 20.0 provided a table of correlation coefficients (Table 9) as an output between each pair of variables listed in the questionnaire, the significance level and the number of cases. Analysis by inferential statistics is concerned with how well the sample data represented the parameters of the population, supported the null hypothesis and enabled the researcher to reject it in favour of the alternative hypothesis (Creswell, 2008). In this research study, a systematic approach was implemented to test hypotheses as guided by Bluman, 2004.

Correlation is significant at 0.05 level (2-tailed). For the purposes of this study, the strength of relationships was determined using the correlation coefficients in three categories according to Pallant (2007) as in Table 3.2.

Table 3.2: Determination of Strength of Relationship Using Correlation Coefficient

Strength of Correlation	**Correlation Coefficient (*r*)**
Small	0.1 – 0.29
Medium	0.3 – 0.49
Large	0.5 – 1.0

(*Source: Pallant, 2007)*

Relationship was considered strong at greater than 0.49 correlation coefficient. Figure 3.3 is a Sanitation Map for Blantyre City showing catchment areas for Blantyre, Soche, Limbe and Chirimba (currently not operational) WWTPs, sewage lines, dams and rivers for information purpose.

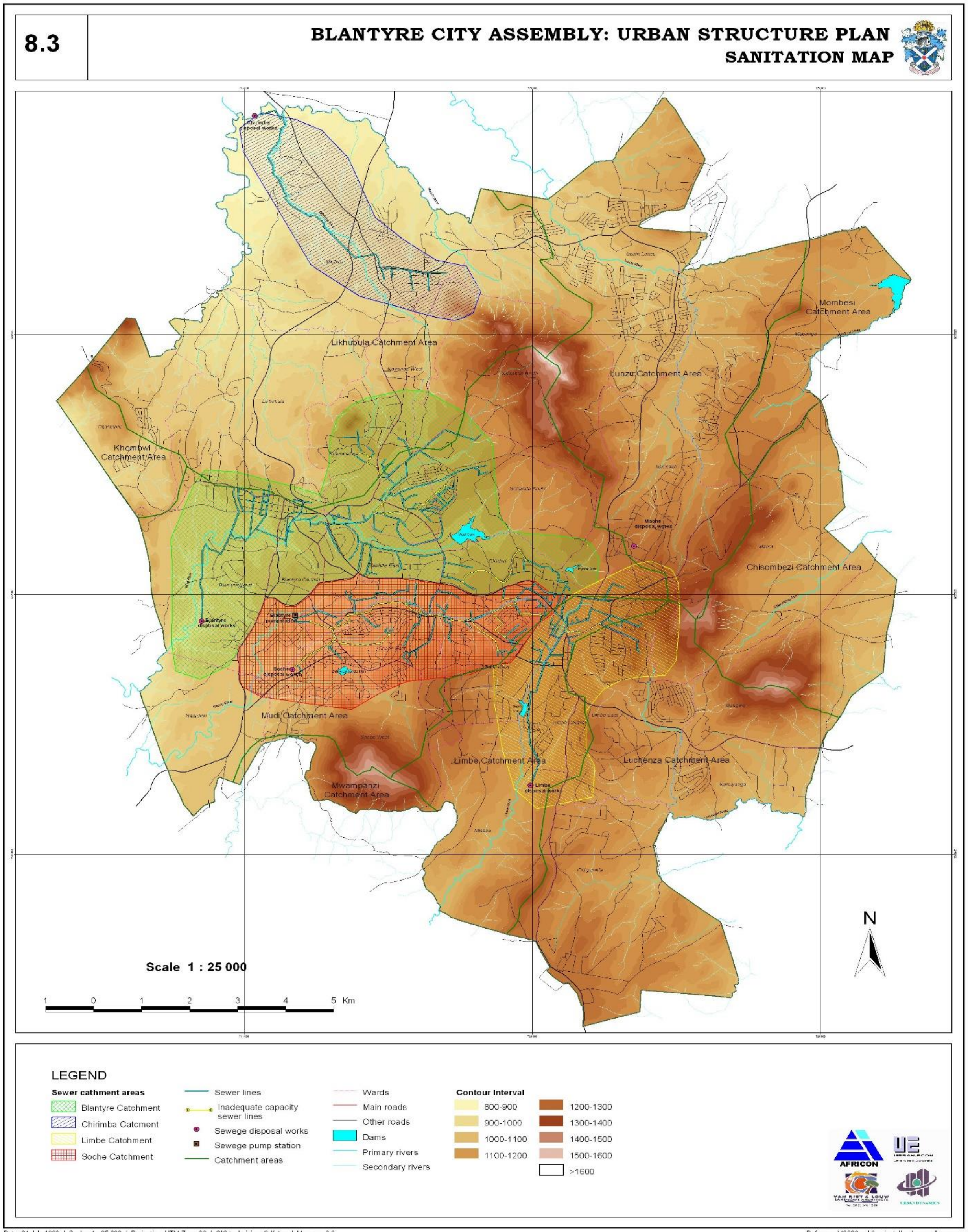

Figure 3.3: Sanitation Map for Blantyre City

(Source: Blantyre Urban Structure Plan. (2000). Blantyre: Blantyre City Council.

3.8 Ethical Consideration

Sources of information and respondents were assured of confidentiality of the information that was provided due to sensitivity of some information collected for this research. All participants that took part in this research were provided with information which enabled them to make informed decision about their participation. The following information was provided:

a) The purpose and objectives of the study with the description of the procedures to be followed.
b) The length of time the researcher needed to get the feedback from respondents.
c) The extent to which results would be confidential.
d) The freedom to withdraw from participation in this study.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Wastewater Disposal Status in Blantyre City

The analysis of multiple response sets at p = 0.05 significance level showed that 23.0% of the total wastewater generated in Blantyre City is discharged into the sewerage system, 33.6% is discharged to septic tanks, 37.6% is discharged into storm water drains which eventually end up into the rivers and ponds and 5.8% is directly discharged into rivers. The results are presented in Table 4.1 and Figure 4.1.

Table 4.1: Analysis of wastewater disposal status in Blantyre City

Wastewater management	Count N (How many times was aspect mentioned)	Column Responses % (Percentage based on answers)
Septic tank	76	33.6%
Sewage	52	23.0%
Storm water drains	85	37.6%
Water bodies	13	5.8%
Total	**183**	**100.0%**

Literature on previous studies about wastewater disposal status in Blantyre City was not available for comparison of results for septic tanks, storm water drains and water bodies. However, it is predicted that Malawi will face a water stress situation by 2025 and that in the city of Blantyre, this situation is aggravated by the serious pollution threat from the grossly inadequate sewage treatment capacity. This capacity is only 23.5% of the wastewater being generated presently (Chipofya, 2010). This compares favourably with the result found in this study on the amount of wastewater that is discharged to the sewage system in view of the serious dilapidation of two wastewater treatment plants in the city namely Limbe and Chirimba WWTPs. These WWTPs are not operational at the time of this study such that Blantyre City's sewage treatment capacity has gone down. Only Soche and Blantyre Wastewater Treatment Plants are operational.

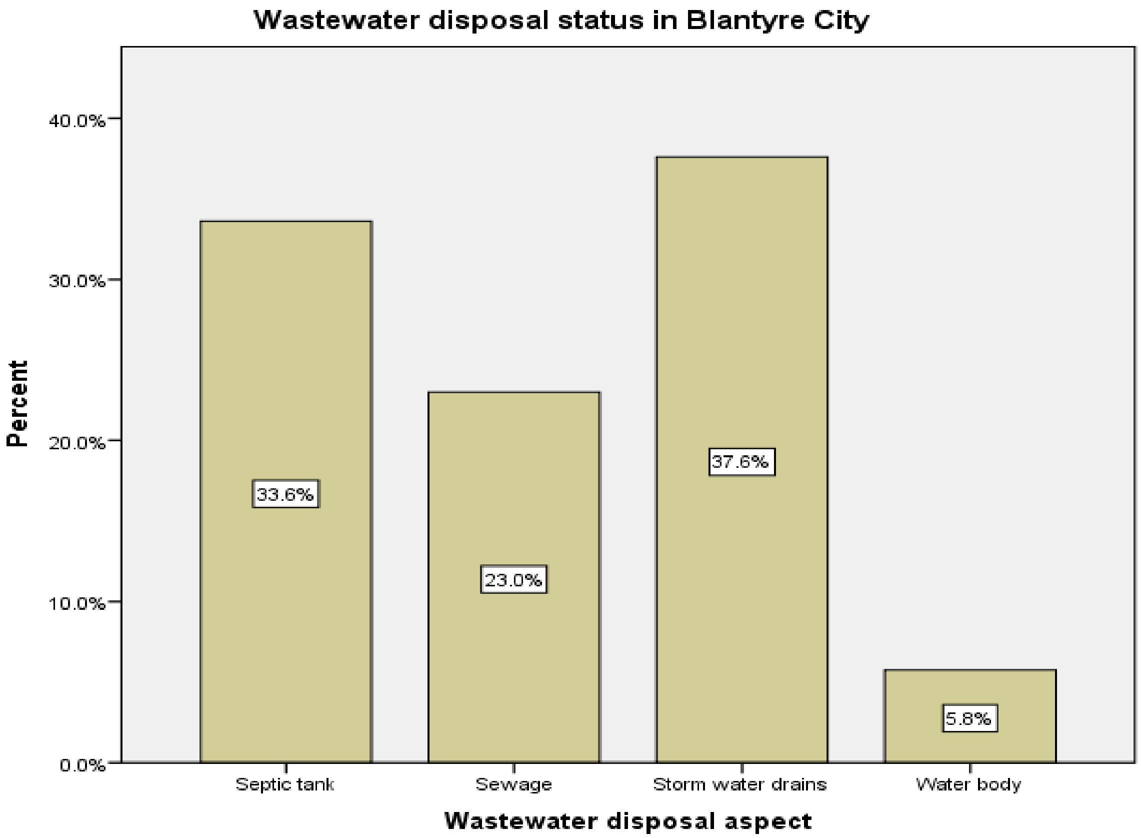

Figure 4.1: Bar graph on Wastewater Management Status in Blantyre City

4.2 Determining Volume of Wastewater Released Per Land Use Category in Blantyre City

It has been determined from the survey data that 25.4% of total population for Blantyre City stays in high-density areas and generates 14,475 m^3 of wastewater per day while 21.3% of total population for Blantyre City stays in medium density areas and generates 24,897 m^3 of wastewater per day whereas 23.7% of total population for Blantyre City stays in low density areas and generates 43,712 m^3 of wastewater per day and finally 23.1% of total population for Blantyre City stays in informal traditional housing areas and generates 9,298 m^3 of wastewater per day.

92,382 m^3 of domestic wastewater is generated per day in the City of Blantyre. The results are summarized in Table 4.2 and Figure 4.2. These results are analyzed using water consumption per capita data as summarized in Table 4.3.

Table 4.28: Domestic wastewater released per residential land use category per day

Residential land use type	Mean wastewater released percapita (l/p/d)	Population percentage based on respondents (Column N %)	Projected 2018 population per residential land use	Domestic wastewater generated per residential type (m^3/day)
High density	52.98	25.4	273,212	14,475
Medium density	108.67	21.3	229,110	24,897
Low density	171.47	23.7	254,926	43,712
Traditional housing area	37.42	23.1	248,472	9,298
Other		6.5		
Total	92.60	100		92,382

Table 4.3: Mean water consumption and wastewater per capita per residential land use

Residential land use type	Mean water consumption per person per day (litres)	Mean wastewater generated per person per day (litres)
High density	58.86	52.98
Medium density	120.75	108.67
Low density	190.52	171.47
Traditional housing area (THA)	41.58	37.42
Total	109.70	92.63

There is a direct relationship between water consumption and domestic wastewater generated per capita, those consuming more water generate more wastewater too. People in low density areas like Nyambadwe, Namiwawa and Sunny Side are the economically well off and can afford to pay for volumes of water above lifeline amount as established by World Health Organization (WHO) seconded by those leaving in the medium density areas like Chinyonga, Chitawira and Naperi. This economic status decreases from low density to traditional housing areas, which are characterized by high poverty levels. The U.S Agency for International Development, the World Bank and the World Health Organization recommend the basic volume of water for drinking and sanitation needs in the range from 20 to 40 litres per capita per day (Zhang, 1999). Gleick in 1996 estimated the basic water requirement at 50 l/p/c/d for meeting four household basic needs: drinking, sanitation, bathing and cooking. Results for mean water consumption per person per day (litres) from the survey for the Traditional housing area (THA) also known as informal settlements land use category are falling within the internationally accepted basic drinking and sanitation requirement range.

There is no literature for past studies on similar topic in Malawi to compare water consumption and sanitation trends, however, results in this study form the basis for future water and sanitation arguments.

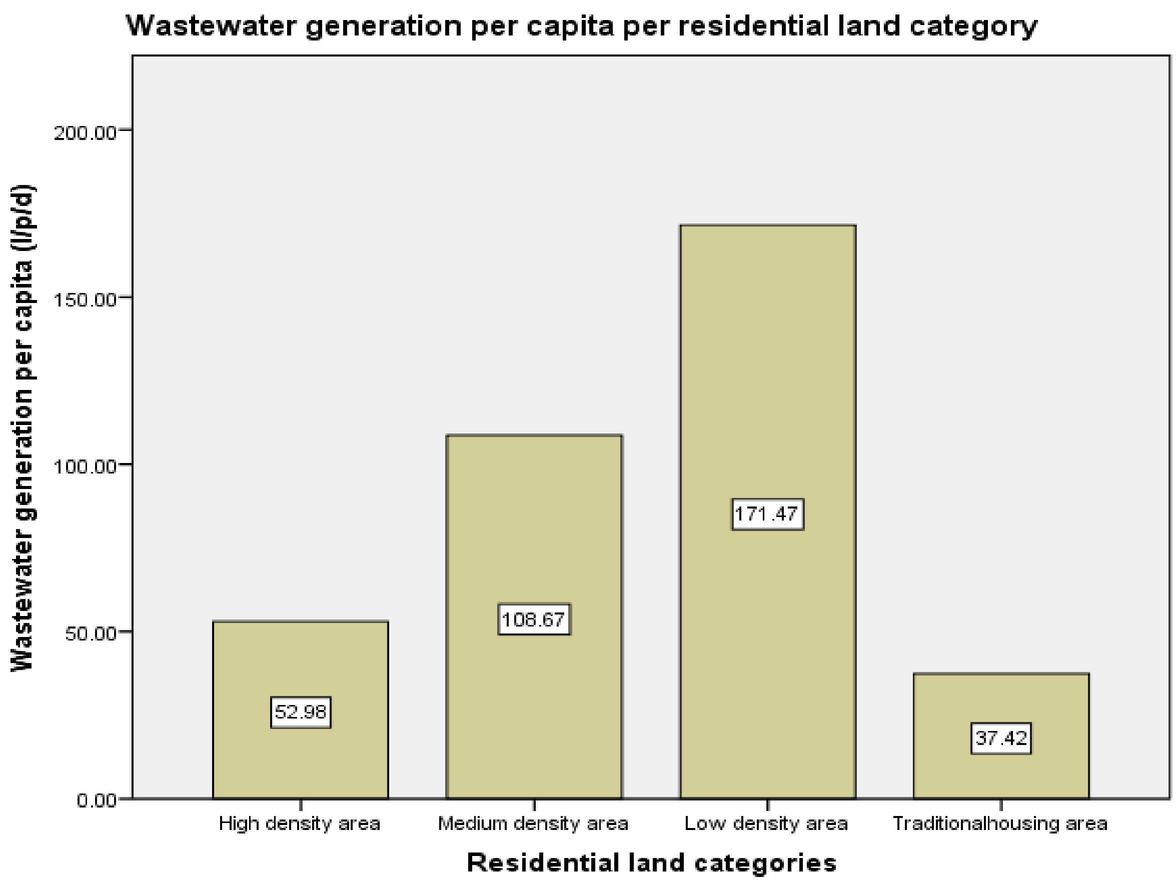

Figure 4.2: Bar graph on wastewater generation per capita per residential land use

4.3 Assessing Water Quality of Effluent Receiving Rivers in Blantyre City before and after Effluent Discharge from Wastewater Treatment Facilities.

4.3.1 Before receiving effluent

The results of water quality laboratory tests of water from Mudi, Naperi, Limbe and Chirimba Rivers before receiving effluent from WWTPs were as below:

4.3.1.1 Mudi River

Table 4.4: Water quality test results for Mudi River before receiving effluent

Mudi River	BOD_5 (mg/l)	COD (mg/l)	TSS (mg/l)	pH	Lead (Pb) (mg/l)	Cadmium (Cd) (mg/l)	Chromium (Cr) (mg/l)	Faecal coliform (Cfu/100ml)
Actual	38	90	168	4.05	0.545	0.069	0.40	32
MBS Guide	20	60	30		0.05	0.005	0.10	0

4.3.1.2 Naperi River

Table 4.5: Water quality test results for Naperi River before receiving effluent

Naperi River	BOD_5 (mg/l)	COD (mg/l)	TSS (mg/l)	pH	Lead (Pb) (mg/l)	Cadmium (Cd) (mg/l)	Chromium (Cr) (mg/l)	Faecal coliform (Cfu/100ml)
Actual	90	192	<0.001	4.08	0.723	0.015	0.48	15
MBS Guide	20	60	30		0.05	0.005	0.10	0

4.3.1.3 Limbe River

Table 4.6: Water quality test results for Limbe River before receiving effluent

Limbe River	BOD_5 (mg/l)	COD (mg/l)	TSS (mg/l)	pH	Lead (Pb) (mg/l)	Cadmium (Cd) (mg/l)	Chromium (Cr) (mg/l)	Faecal coliform (Cfu/100ml)
Actual	23	57.6	<0.001	4.66	0.243	0.045	0.44	5
MBS Guide	20	60	30		0.05	0.005	0.10	0

4.3.1.4 Chirimba River

Table 4.7: Water quality test results for Chirimba River before receiving effluent

Chirimba River	BOD_5 (mg/l)	COD (mg/l)	TSS (mg/l)	pH	Lead (Pb) (mg/l)	Cadmium (Cd) (mg/l)	Chromium (Cr) (mg/l)	Faecal coliform (Cfu/100ml)
Actual	193.2	384	1023	4.08	1.084	0.725	3.30	228
MBS Guide	20	60	30		0.05	0.005	0.10	0

4.3.2 After Receiving Effluent

The samples were collected downstream of a wastewater, treatment plant after effluent was discharged into the rivers and below were the specific point locations:

4.3.2.1 Mudi River

Table 4.8: Water quality test results for Mudi River after receiving effluent

Mudi River	BOD_5 (mg/l)	COD (mg/l)	TSS (mg/l)	pH	Lead (Pb) (mg/l)	Cadmium (Cd) (mg/l)	Chromium (Cr) (mg/l)	Faecal coliform (Cfu/100ml)
Actual	79	172	13	4.12	0.481	0.074	0.63	2
MBS Guide	20	60	30		0.05	0.005	0.10	0

4.3.2.2 Naperi River

Table 4.9: Water quality test results for Naperi River after receiving effluent

Naperi River	BOD_5 (mg/l)	COD (mg/l)	TSS (mg/l)	pH	Lead (Pb) (mg/l)	Cadmium (Cd) (mg/l)	Chromium (Cr) (mg/l)	Faecal coliform (Cfu/100ml)
Actual	68	130	<0.001	4.05	0.799	0.165	0.22	3
MBS Guide	20	60	30		0.05	0.005	0.10	0

4.3.2.3 Limbe River

Table 4.10: Water Quality Test Results for Limbe River after Receiving Effluent

Limbe River	BOD_5 (mg/l)	COD (mg/l)	TSS (mg/l)	pH	Lead (Pb) (mg/l)	Cadmium (Cd) (mg/l)	Chromium (Cr) (mg/l)	Faecal coliform (Cfu/100ml
Actual	11	28	<0.001	5.01	0.337	0.44	0.25	30
MBS Guide	20	60	30		0.05	0.005	0.10	0

The results are summarised in Table 4.11:

Table 4.11: Summary Results of Laboratory Tests on Water Samples from Mudi, Naperi, Limbe and Chirimba Rivers

	BOD_5 (mg/l)	COD (mg/l)	TSS (mg/l)	pH	T°C	Cadmium (Cd) (mg/l)	Chromium (Cr) (mg/l)	Lead (Pb) (mg/l)	Total Coliform (fitration method) (Cfu/100ml)	Total Coliform (MPN-Colilert Method) (Cfu/100ml	Faecal Coliform (fitration method) (Cfu/100ml)	Faecal Coliform (MPN-Colilert Method)
Mudi River												
Upstream	38	90	168	4.17	24.9	0.069	0.40	0.545	TNTC	525	TNTC	32
Downstream	79	172	13	4.12	19.2	0.074	0.63	0.481	TNTC	152	TNTC	2
Limbe River												
Upstream	23	57.6	<0.001	4.66	23.6	0.045	0.44	0.243	TNTC	96	TNTC	5
Downstream	11	28	<0.001	5.01	26.7	0.44	0.25	0.337	TNTC	260	TNTC	30
Naperi River												
Upstream	90	192	<0.001	4.08	25.28	0.015	0.48	0.723	TNTC	59	TNTC	15
Downstream	68	130	<0.001	4.05	25.08	0.165	0.22	0.799	TNTC	27	TNTC	3

Chirimba River												
Upstream	193.2	384	1023	4.08	25.3	0.725	3.30	1.084	TNTC	1011	TNTC	228
Downstream	-	-	-	-	-	-	-	-				
MBS Guideline	20	60	30			0	0	0	0	0	0	0
WHO Guide	20	60	30			0	0	0	0	0	0	0

<u>Key</u>

TNTC : Too numerous to count

Cfu : Colony forming units

MPN : Most probable number

(Tested at University of Malawi - The Polytechnic. Sampling was done on 17 November 2018. Testing and analysis of results was conducted from 19 November 2018 to 23 November 2018. Compilation of results was done on 4 December 2018)

4.3.3 Water Quality in Rivers Upstream and Downstream of WWTPs

The results show that rivers in Blantyre City are polluted by wastewater. Pollution load in the rivers is above recommended guidelines set by Malawi Bureau of Standards (MBS) and World Health Organization (WHO). For instance, mean laboratory test results of water samples collected at different points to the upstream of wastewater treatment plants (WWTP) in Limbe, Naperi and Mudi Rivers showed higher levels of BOD_5, COD and TSS than set limits by regulating agencies (MBS and WHO). Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS) are indicators of wastewater contamination (Kaonga et al., 2013). Therefore, water in Mudi, Naperi, Limbe and Chirimba Rivers in the City of Blantyre is already in polluted state with wastewater before wastewater treatment plants discharge effluent into them as shown, henceforth.

4.3.3.1 Levels of BOD_5, COD and TSS in Mudi River before effluent discharge

In November 2018, the mean values were: 38 mg/l (BOD_5), 90 mg/l (COD) and 168 mg/l (TSS). The magnitude of the values are higher than MBS guideline values which are: 20 mg/l (BOD_5), 60 mg/l (COD) and 30 mg/l (TSS). It is clear from these results that water in Mudi River is already in polluted state before receiving effluent discharge from Blantyre Wastewater Treatment Plant as already observed in Table 4.4.

Mudi River originates from the southern slopes of Ndirande Mountain (Jedde, 2013) and its catchment area is badly deforested. Mudi River combines with other tributaries namely Namichimba, Nkanabodza and Telefoni before entering into Mudi Dam which is owned by Blantyre Water Board. From Mudi Dam, the river runs between Makata and Ginnery Corner heavy industrial sites where it receives wastewater from domestic and industrial activities discharged into the it either directly or indirectly through leaking sewage pipes. Mudi River is joined by Nasolo Stream in Makata Industrial Site. Nasolo Stream originates from Ndirande Mountain and it runs through Ndirande squatter residential areas, collecting wastewater from that side into Mudi River.

From the industrial sites named above, Mudi River passes through Blantyre Central Business District (CBD) and its heavy pollution load can be noticed from the odour coming from the passing waters. The river passes through Sunnyside Residential Area before receiving effluent from Blantyre Wastewater Treatment Plant already polluted by wastewater as the laboratory results show.

4.3.3.2 Levels of BOD_5, COD and TSS in Naperi River before effluent discharge

In November 2018, the mean values were 90 mg/l (BOD_5), 192 mg/l (COD) and <0.001 mg/l (TSS). BOD_5 and COD results magnitude exceeds the MBS guideline values, which are 20mg/l (BOD_5) and 60mg/l (COD). However, TSS results were lower than MBS limit of 30 mg/l (TSS). This suggests that turbidity of the water on the day of sampling was low mainly because of good vegetative cover along the riverbanks. Nevertheless, it is clear from these results that that water in Naperi River is already in polluted state before receiving effluent discharge from Soche Wastewater Treatment Plant as already observed in Table 4.5.

Naperi River originates from Maselema Area and receives wastewater load emanating from both domestic and industrial activities from Maselema Industrial Site, Kanjedza, Chitawira, Zingwangwa, Old and New Naperi Residential Areas. Wastewater is either directly or indirectly discharged into the river through leakages from pipes or blocked chambers of sewage network.

As the river approaches Soche Wastewater Treatment Plant (WWTP) its heavy pollution load can be noticed from the odour coming from the passing waters. The river passes between Zingwangwa and New Naperi Townships as it approaches Soche Wastewater Treatment Plant already polluted by wastewater as the laboratory results show.

4.3.3.3 Levels of BOD_5, COD and TSS in Limbe River before effluent discharge

In November 2018, the mean values were 23 mg/l (BOD_5), 57.6 mg/l (COD) and <0.001 mg/l (TSS). BOD_5 result exceeds the MBS guideline values, which is 20mg/l (BOD_5). However, COD and TSS results were lower than MBS limit of 30 mg/l (TSS) and 60 mg/l (COD). This suggests partial wastewater contamination at the sampled point. Turbidity of the water on the day of sampling was low mainly because of good vegetative cover along the river banks from Chigumula going downstream which effects dilution of pollution load over the distance (Jedde, 2014). It is clear from these results that that water in Limbe River is already in polluted state, though partially, before receiving effluent discharge from Limbe Wastewater Treatment Plant as already observed in Table 4.6.

Limbe River originates from the Mpingwe Hills in the eastern side of Limbe Town. It flows down from Mpingwe through Limbe Central Business District (CBD) crossing Chiwembe, Chigumula and Manje residential areas as it exits Blantyre City on its way to join Mudi River. The river receives wastewater from domestic and industrial activities discharged into it directly from homes and industries and indirectly through leaking sewage pipes.

Limbe River passes through Limbe Market as it exits the Central Business District (CBD) and its heavy pollution load can be noticed from the odour coming from the passing waters as it crosses Dalton Road near the market.

4.3.3.4 Levels of BOD_5, COD and TSS in Chirimba River before effluent discharge

In November 2018, the mean values were 193.2 mg/l (BOD_5), 384 mg/l (COD) and 1023 mg/l (TSS). The magnitude of the results are higher than set MBS guideline values, which are 20 mg/l (BOD_5), 60 mg/l (COD) and 30 mg/l (TSS). This clearly indicates that water in Chirimba River is in heavily polluted state before receiving effluent discharge from Chirimba Wastewater Treatment Plant as already seen in Table 4.7.

Chirimba River originates from the northern slopes of Ndirande Mountain and its catchment area is badly deforested. The river runs through north western side of Ndirande squatter residential area, Chirimba Industrial Site and Chirimba Residential Area where it receives heavy load of wastewater from domestic and industrial activities within its catchment area discharged directly into it due to unavailability of a functioning sewage system. From the residential areas and industrial site named above, Chirimba River flows down the escarpments of Michiru Hills with its heavy pollution load, noticed from the odour coming from the passing waters, before effluent from Chirimba Wastewater Treatment Plant can be discharged into it. The water is already polluted by wastewater as the laboratory results show. The results show that Chirimba River is the most polluted river out of the four.

4.3.3.5 Levels of hard metals: Cd, Pb and Cr in Mudi River before effluent discharge

In November 2018, the mean values were 0.069 mg/l (Cd), 0.545 mg/l (Pb) and 0.40 mg/l (Cr). This is against set MBS guideline values, which are 0.005 mg/l (Cd), 0.05 mg/l (Pb) and 0.10 (Cr). It is clear from these results that that water in Mudi River contains high levels of Cadmium, Lead and Chromium pollution as observed in Table 4.4. An elevated level of these hard metals in water is directly hazardous to aquatic life and indirectly to human beings as they are toxic and non-biodegradable. They bio accumulate in bodies of living beings and are passed on through food chains. The presence of lead, chromium and cadmium in the water in Mudi River under this study could be traced to industrial effluents from Printing, Paint, Textile, Matches, Edible Oil, Diary, Abattoir, Motor Oil and Fertilizer Manufacturing Companies within its catchment area (Kuyeli, 2007). Within Makata and Ginnery Corner Industrial Areas some of the companies where Lead, Chromium and Cadmium can be traced to are: Blantyre Printing and Packaging, Blantyre Newspapers Limited, Mapeto David Whitehead and Sons Textile Company, Leopard Match Company, Kukoma Oil Company, Dairy Board Limited, S & A Cold Storage Company, Toyota Malawi and Optichem Fertiliser Company. The results agree with past studies done by Kuyeli, (2007).

Lead is toxic in most of its chemical forms and enters human body through inhalation, ingestion, skin contact and absorption. Excessive exposure of lead above safe levels (below 0.05 mg/l) affects development of the brain and nervous system in young children. It increases risk of high blood pressure and kidney damage in adults in the long term (WHO, 2007)

Chromium contaminated water at levels above drinking water standard (below 0.1 mg/l) may damage liver, kidney, blood circulatory system, nerve tissues as well as causing dermatitis (Kuyeli, 2007). Cadmium exposure above safe levels (below 0.005 mg/l) may impair lung function and has been associated with borne disease (Cadmium Association, UK; Cadmium Council, USA, 1991).

4.3.3.6 Levels of hard metals: Cd, Pb and Cr in Naperi River before effluent discharge

In November 2018, the mean values were 0.015 mg/l (Cd), 0.723 mg/l (Pb) and 0.48 mg/l (Cr). This is against set MBS guideline values, which are 0.005 mg/l (Cd), 0.05 mg/l (Pb) and 0.10 (Cr). It is clear from these results that that water in Naperi River contains high levels of Cadmium, Lead and Chromium pollution (Table 4.5).

The presence of lead, chromium and cadmium in the water in Naperi River under this study could be traced to industrial effluents from Printing, Paint, Textile, Matches, Edible Oil, Diary, Abattoir, Motor Oil and Fertilizer Manufacturing Companies within the rivers catchment area (Kuyeli, 2007).

The catchment area for Naperi River includes Maselema and Chitawira light industrial sites within which some of the companies where Lead, Chromium and Cadmium can be traced to are: Toyota Malawi in Maselema where used motor oil after servicing vehicles if not properly pre-treated can pollute water in nearby Naperi River, Fernandez Motors, Rab Processors Limited and Tata Trucking Limited, just to mention but a few. The results agree with past studies done by Kuyeli, (2007).

4.3.3.7 Levels of hard metals: Cd, Pb and Cr in Limbe River before effluent discharge

At the beginning of the rainfall season in November 2018, the mean values were 0.045 mg/l (Cd), 0.243 mg/l (Pb) and 0.44 mg/l (Cr). This is against set MBS guideline values, which are 0.005 mg/l (Cd), 0.05 mg/l (Pb) and 0.10 (Cr). It is clear from the results that that water in Limbe River contains high levels of Cadmium, Lead and Chromium pollution (Table 4.6).

The presence of lead, chromium and cadmium in the water in Limbe River under this study could be traced to industrial effluents from Printing, Paint, Textile, Matches, Edible Oil, Diary, Abattoir, Motor Oil and Fertilizer Manufacturing Companies within the rivers catchment area (Kuyeli, 2007).

The catchment area for Limbe River includes Mpingwe, Limbe CBD, Limbe Market, Chigumula, Chiwembe and Manje. Activities by companies and communities within the catchment can be attributed to Lead, Chromium and Cadmium pollution in Limbe River. For instance, small and medium scale entrepreneurs operating motor garages where used oils and paints are not pretreated before disposal, formal and informal restaurants spread within and around Limbe CBD dispose of used cooking oil which ends into the river.

4.3.3.8 Levels of hard metals: Cd, Pb and Cr in Chirimba River before effluent discharge

In November 2018, the mean values were 0.725 mg/l (Cd), 1.084 mg/l (Pb) and 3.30 mg/l (Cr). This is against set MBS guideline values, which are 0.005 mg/l (Cd), 0.05 mg/l (Pb) and 0.10 (Cr). It is clear from the results that that water in Chirimba River contains high levels of Cadmium, Lead and Chromium pollution (Table 4.7).

Chirimba River originates from the northern slopes of Ndirande Mountain. It runs through northwestern side of Ndirande squatter residential area, Chirimba industrial site and Chirimba residential area. These three hard metals can be traced to human economic activities for small, medium and large-scale entrepreneurs operating motor garages, engineering fabrication shops and restaurants within the catchment area where used oils and paints are not pretreated before disposal. This is in addition to manufacturing activities taking place in Chirimba Industrial Site by Kukoma Oil Company, Polyplast Limited, Chirimba Cable Manufacturing Company and Henred.

4.3.4 Water Quality Status in Rivers Downstream of Wastewater Treatment Plants

Wastewater treatment plants (WWTPs) in Blantyre City release effluent of poor quality into the rivers (Blantyre City Council, 2018). Laboratory tests results on effluent discharged by Blantyre, Soche and Limbe Wastewater Treatment plants for both wet and dry seasons for BOD_5, COD and TSS were found to be higher than guideline figure set by MBS and WHO. The levels of their efficiency are indicated in Tables 2.3 and 2.4 (Chipofya et al, 2009). The results show that wastewater treatment plants in Blantyre are contributing to the pollution load in the rivers.
Surface water quality status in Mudi, Naperi, Limbe and Chirimba Rivers after effluent discharge is highlighted in the following sections:

4.3.4.1 Levels of BOD_5, COD and TSS in Mudi River after effluent discharge

In November 2018, the mean values were 79 mg/l (BOD_5), 172 mg/l (COD) and 13 mg/l (TSS). This is against set MBS guideline values which are 20mg/l (BOD_5), 60 mg/l (COD) and 30mg/l (TSS). It is clear from these results that that effluent from Blantyre WWTP is increasing pollution load in the river, for instance before effluent discharge BOD_5 was 38 mg/l and has gone up to 79 mg/l after effluent discharge. However, compliance on TSS test was noted probably due to dilution effect due to flowing distance and vegetative cover on the riverbanks (Luka, 2013). This can be referred to Table 4.8.

4.3.4.2 Levels of BOD_5, COD and TSS in Naperi River after effluent discharge

In November 2018, the mean values were 68 mg/l (BOD_5), 130 mg/l (COD) and <0.001 mg/l (TSS). MBS guideline values are 20mg/l (BOD_5), 60 mg/l (COD) and 30mg/l (TSS). The results show higher levels of BOD_5 and COD than set limit. This indicates wastewater pollution. It is also noted that there is a slight reduction in pollution levels as indicated by the three parameters before and after effluent discharge into Naperi River. For instance before effluent discharge BOD_5 was 90 mg/l and has gone down to 68 mg/l after effluent discharge, though still in polluted state. However, compliance on TSS test was noted probably due to dilution effect (Luka, 2013). This can be referred to in Table 4.9.

4.3.4.3 Levels of hard metals: Cd, Pb and Cr in Mudi River after effluent discharge

In November 2018, the mean values were 0.074 mg/l (Cd), 0.481 mg/l (Pb) and 0.630 mg/l (Cr). This is against set MBS guideline values, which are 0.005 mg/l (Cd), 0.05 mg/l (Pb) and 0.10 (Cr). It is clear from these results that that water in Mudi River remains polluted with high levels of Cadmium, Lead and Chromium downstream Blantyre Wastewater Treatment Plant (Table 4.8).

4.3.4.4 Levels of hard metals: Cd, Pb and Cr in Naperi River after effluent discharge

At the beginning of the rainfall season in November 2018, the mean values were 0.165 mg/l (Cd), 0.799 mg/l (Pb) and 0.22 mg/l (Cr). This is against set MBS guideline values, which are 0.005 mg/l (Cd), 0.05 mg/l (Pb) and 0.10 (Cr). It is clear from these results that that water in Naperi River remains polluted with high levels of Cadmium, Lead and Chromium downstream Soche Wastewater Treatment Plant (Table 4.9). The presence of lead, chromium and cadmium in the water in rivers under this study downstream of the wastewater treatment plant can be largely traced to the economic activities taking place to the upstream like industrial effluents from Printing, Paint, Textile, Matches, Edible Oil, Diary, Abattoir, Motor Oil and Fertilizer Manufacturing Companies in the City of Blantyre (Kuyeli, 2007) in addition to activities of small and medium scale entrepreneurs operating motor garages, restaurants and engineering fabrication shops within the city as already discussed.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study has shown how wastewater is disposed in the city of Blantyre. It has also determined the amount of domestic wastewater generated per day per residential land use category. The study checked water pollution levels in the rivers that receive effluent from wastewater treatment plants by conducting laboratory tests on water samples taken upstream and downstream of wastewater treatment plants. Pollution levels were tested by analysing BOD_5, COD, TSS, Total coliforms, FCB and heavy metals: Pb, Cd and Cr in the water samples.

The study has revealed that only 23.0% of the total wastewater generated in Blantyre City is conveyed to the wastewater treatment plants for treatment and disposal, 37.6% to the storm water drains, 33.6% to the septic tanks and 5.8% of the total generated wastewater is directly disposed into the rivers. It is evident that 43.4% (37.6% storm water drains added to 5.8% rivers) of the total wastewater generated in the city of Blantyre end up in rivers therefore polluting surface water, while, 33.6% which is discharged to the septic tanks is potentially polluting underground water resources in the city.

The study has also estimated amount of wastewater generated per day per residential land category namely; high density, medium density, low density and traditional housing areas. A total of 92,382m^3 of domestic wastewater is generated per day. This is a summation of 14,475m^3 per day for high-density areas, 24,897m^3 per day for medium density areas, 43, 712 m^3 per day for low-density areas and 9,298m^3 per day for traditional housing areas also known as informal settlements.

Results of laboratory tests analysis have shown that all rivers in Blantyre City are polluted by wastewater throughout the year. Pollution load in the rivers is above recommended guidelines set by MBS and WHO. For instance, mean laboratory test results of water samples collected at different points to the upstream and downstream of WWTPs in Mudi, Naperi, Limbe and Chirimba Rivers at the beginning of the rainy season in November 2018 show higher levels of BOD_5, COD and TSS than set limits by regulating agencies (MBS and WHO). BOD_5, COD, and TSS are indicators of wastewater contamination.

5.2 Recommendations

Wastewater management in Malawi is getting out of hand because of lack of guiding policies on domestic wastewater disposal. Current policies and regulations target mostly management of sewage and industrial effluents, however, the survey has revealed serious capacity challenges in sewage management. Sewage treatment plants manage only 23.0% of the total wastewater generated. The larger proportion of wastewater is disposed to the storm water drains, septic tanks and surface water bodies unregulated. This is polluting water resources and the environment. The following recommendations are made to bring efficiency and effectiveness in this area:

5.2.1 Wastewater recycling and re-use should be encouraged as a water resources conservation strategy.

Wastewater should be considered as a renewable resource within the hydrological cycle. The water recycled by natural systems provides a clean and safe resource, which becomes degraded by different levels of pollution. Recycled wastewater can be used for urban irrigation of public parks, playgrounds, flower lawns, firefighting, construction, air conditioning, boiler feed water, toilet and urinal flushing and aesthetic purposes like fountains, waterfalls and other decorative water features. Although constraints of using wastewater for non-potable re-use are usually related to high costs involved in the construction of dual water distribution networks, operational challenges and likelihood of cross – connection, the costs are balanced by the benefits of conserving water resources and eventually delaying or cancelling the need for the development of new water sources or expanding existing water supply networks.

5.2.2 Government must upgrade capacity of wastewater treatment plants (WWTPs) in urban centres.

The study has revealed capacity challenges of the existing wastewater treatment facilities in the city of Blantyre. They treat only 23% of total wastewater generated in the city. The government needs to identify funding for upgrading works of WWTPs in the country. Since local councils currently manage wastewater, it becomes a challenge for the local councils to find investors, as there is hardly an assurance that the cost of either rehabilitation or construction of wastewater treatment plants could be recovered (Blantyre City Council, 2018). Their only source of funding is the government.

5.2.3 Specifications and minimum standards must be issued for the use of septic tanks with particular attention paid to the protection of underlying aquifers

Septic tanks treat and dispose of household wastewater on site. They are more economical than centralized WWTPs. According to the survey, 33.6% of wastewater is discharged to the septic tanks. Septic system failures however, have caused pollution of ground water, river and streams. To enhance their effectiveness, adequate regulations or guidelines for septic tank design, construction and installation must be put in place.

5.2.4 Laboratories in wastewater treatment stations must be stocked with adequate and modern equipment

Laboratories must be maintained and properly equipped to provide reliable data needed to ensure enforcement of and adherence to standards and regulations. Efficient and well-maintained laboratories are key to enforcement of wastewater quality standards. They are valuable to standards compliance enforcement efforts by providing a sound scientific basis for environmental management decisions, ensuring protection of the environment in a cost effective manner, strengthening legal defensibility of regulatory actions and keeping staff current with scientific and technological advances.

5.2.5 Public awareness on risks associated with untreated wastewater handling must be enhanced

The public must be educated through various means about the risks associated with exposure to untreated wastewater and the value of treated effluents. It is important to educate the public on the aspects of wastewater management. Most people are not aware of the complexities involved in providing wastewater treatment services to prevent the contamination of drinking water sources. Every water user contributes to the body of wastewater and has a role in preventing impacts associated with improper disposal of it. Programmes on farmers' awareness shall promote the re-use of treated wastewater, methods of irrigation and handling of farm produce. Due to increasing water shortages, farmers use diluted wastewater to irrigate vegetables and other crops along riverbanks in the city of Blantyre and other urban areas in Malawi. Farmers need awareness of health risks associated with this act including how to use wastewater safely at farm level.

5.2.6 Government should subsidise the cost of sanitary wares to make them affordable to a large proportion of the population to improve sanitation in Malawi.

Due to population growth and rapid urbanization in Malawi, more urbanized centres are facing difficulties in coping with ever-increasing demand for sanitation services. The study has revealed that 37.6% of wastewater generated in Blantyre City is directly disposed to the storm water drains. This is a sanitation lapse and there is need to find innovative solutions to address this challenge. A broad range of cost-effective sanitation technologies are available to respond to wastewater management demand. Examples range from ventilated improved pit (VIP) latrines, pour-flush latrines, condominium sewers to simplified sewage. There is flexibility to choose a range of technologies available depending on specific objectives to be addressed, for instance; operational efficiency, regulatory compliance, cost efficiency and resource recovery. However, the cost is high to be afforded by most people especially low-income city dwellers. It is important that Government should subsidize the cost of sanitary wares and materials in order to help this group of people construct improved sanitation facilities.

5.3 Areas of Further Study

There is need to conduct further research in the following areas in order to support the findings and recommendations of this study:

5.3.1 Do a feasibility study on proposed upgrading works of wastewater treatment plants in Blantyre to be able to treat at least 50% of total generated domestic wastewater using baseline established in this study. Develop the selected option by producing the following documents:

5.3.1.1 Engineering design report including financial appraisal and cost estimates

5.3.1.2 Engineering drawings

5.3.1.3 Bidding documents

REFERENCES

Agrifor Consultant. (2006). *Country environmental profile for Malawi.* Belgium: Consortium AFC.

Asian Development Bank. (2001). *The Water Policy of the Asian Development Bank.* Retrieved from http://www.adb.org

Barker, E., Bos, R., Corcoran, E., Nellemann, C., & Osborn, D. (2010). *Sick water? The Central role of wastewater management in sustainable development. A rapid responce assessment.* Geneva: UNEP/UN-Habitat.

Baul, T., Sara, R., & Srinivas, P. (1992). Simultaneous determination of trace heavy metals in waters by atomic absorption spectrometry after preconcentration by solvent extraction. *Journal of Environmental Analytical Chemistry, 25*(8).

Blantyre City Council. (2018). *The status of the sewage system in the city of Blantyre.* Blantyre: Author. Retrieved December 11, 2018

Braun, U., Oldenburg, M., & Otterpohl, R. (2004). Innovative technologies for decentralised water, wastewater and biowaste management in urban and peri-urban areas. *Water Science Technology, 48*(11-12), 23-32.

Cadmium Association, UK; Cadmium Council, USA. (1991). *Technical notes on cadmium: cadmium production, properties and uses.* London: Cadmium Association. Retrieved from www.cadmium.org>enviroment

Chipofya, V. K. (2010, June). Comparison of pollutant levels in effluent wastewater treatment plants in Blantyre, Malawi. *International Journal of Water Resources and Environmental Engineering, 2*(4), 79-86. Retrieved from http://www.academicjournals.org/ijwree

City of Guelph. (n.d.). *Introduction to wastewater treatment.* Guelp: Author.

de Albuquerque, C. (2014). *Realising the human rights to water and sanitation.* Retrieved from http://www.righttowater.info/handbook

Department of Environment, Food and Rural Affairs, UK. (2012). *National Policy Statement for Wastewater.* Retrieved from https://www.gov.uk/government/publications

Department of Environmental Protection. (2012). *Reuse of treated wastewater guidance manual.* Pennsylvania: Author. Retrieved from http://www.elibrary.dep.state.pa.us/dsweb

Heymans, C. M. (2004). Driving policy change for decentralised wastewater management. Retrieved from http://wedc.lboro.ac.uk/resources

Institute for Resource Analysis and Policy. (2012). *Toolkit for integrated urban water management.* Dheli: IRAP. Retrieved from http://www.indiawaterportal.org/articles/toolkit

Kuyeli, S. (2007). *Assessment of industrial effluents and their impacts on water quality in streams of Blantyre City, Malawi.* Zomba: Faculty of Science, University of Malawi.

Lakudzala, D. T. (1999). An investigation of chemical pollution in Lower Shire River, Malawi. *Malawi Journal of Science and Technology, 5*(1), 87-94.

Madyiwa, S. C. (2003). Greenhouse studies on the phytoextraction capacity of cynodon nlemfluensis for Lead and Cadmium under irrigation with treated wastewater. *Physics and Chemistry of the Earth, 28(1),* 859-867.

Malawi Bureau of Standards. (2005). *Malawi Standard: Drinking water specification.* Blantyre: Author.

Malawi Government. (1994). *Malawi National Environmental Action Plan.* Lilongwe: Author.

Malawi Government. (1995). *Sanitation Master Plan Study for the City of Blantyre Vol 3.* Lilongwe: Author.

Malawi Government. (2005). *National Water Policy*. Lilongwe: Ministry of Irrigation and Water Development

Malawi Standards Board. (2005). *MS 214:2005, ICS 13.030.40 (First revision).* Blantyre: Author.

Mkandawire, T. M. (2008). A preliminary study of the efficiency of Soche Wastewater Treatment Plant, Blantyre, Malawi: Compliance of final effluent with design and WHO recommended standards. *Environment and Health International, 10*(2), 8-10.

Mtethiwa, A. M. (2007). Efficiency of oxidation ponds in wastewater treatment. *International Journal of Environment Res, 2*(2), 149-152.

Nema, N., Maity, N., & Sarkar, B. (2012). Determination of trace and heavy metals is some commonly used medicine herbs in Ayurveda. *Toxicology and Industrial Health, 30*(10), 964-968.

Paerl, H. (1997). Coastal eutrophication and harmful algal bloom: Importance of atmospheric deposition and groundwater as new nitrogen and other nutrient sources. *Limnology and Oceanography*, *42*(5 part 2), 1145-1165.

Sajidu, S. M. (2007). Water quality assessment in streams and wastewater treatment plants of Blantyre, Malawi. *Physics and Chemistry of the Earth, 32*(1), 1391-1399.

Srikanth, P., Somarsekhar, S., & Kanthi, G. a. (2013, March). Analysis of heavy metals by using atomic absorption spectroscopy from the samples taken around Visakhapatnam. *International Journal of Environment, Ecology, Family and Urban Studies (IJEEFUS), 3*(1), 127-132.

UN Water. (2013). *Thematic consultation on wastewater management and water quality: Water resources management and wastewater management.* Geneva: UN Water. Retrieved from https://www.unece.org/post

UN-Habitat, U.-E. A. (2015). Policy guidance manual on wastewater management with a special emphasis on decentralised wastewater treatment systems. Bangkok: United Nations.

United Nations. (2017). *Sustainable Goals.* Washington: Author. Retrieved November 14, 2017, from www.un.org/sustainablegoals

UN-Water. (2015). *Wastewater Management: A UN-Water Analytical Brief.* Geneva: Author.

World Health Organisation. (2007). *Health risks of heavy metals from long-range transboundary air pollution.* Copenhagen: WHO Regional Office. Retrieved from www.who.int>fact-sheets>detail

APPENDICES

APPENDIX 1: QUESTIONNAIRE

The Polytechnic

This questionnaire has been prepared for academic purposes only towards establishing wastewater disposal status in Malawi based on the city of Blantyre as a case study in partial fulfilment for the award of the Degree of MSc in Infrastructure Development and Management of the University of Malawi. Identities of respondents other than gender and qualification will not be revealed to any third party or contained in the report thereto.

PART A: CHARACTERISATION OF THE PROFILE OF THE RESPONDENT

(*Please tick where applicable in the boxes provided*)

1. What is your gender? Please tick box

   Male: ☐

   Female: ☐

2. What is your level of education? Please tick appropriate box.

   a. Tertiary level ☐
   b. Secondary level ☐
   c. Primary level ☐
   d. No formal education ☐

3. What are the names of your facility (e.g. residential house, institution or industry) and location?

   Name of facility ____

   Name of location of the facility ____

<u>PART B:</u> <u>EXPLORING WASTEWATER DISPOSAL STATUS PER LAND-USE CATEGORY</u>

(*Please tick where applicable in the boxes provided*)

4. Referring to Question 3, which land use category does your location fall in.

   a. Residential ☐

   b. Commercial ☐

   c. Institutional ☐

   d. Industrial ☐

5. In relation to Question 4, option (a), which residential land use category does your location fall in?

   a. High density area ☐

   b. Medium density ☐

   c. Low density area ☐

   d. Traditional housing area (THA) ☐

6. What do you use water for at this facility? *Please tick box (es). Multiple response is possible*

   a. Domestic chores (cooking, bathing, laundry, cleaning) ☐

   b. Agriculture ☐

   c. Industrial processing ☐

   d. Fire fighting ☐

   e. Other (please specify) ☐

7. What type of wastewater is generated at this location?
    a. Domestic wastewater ☐
    b. Industrial wastewater ☐
    c. Agricultural wastewater ☐
    d. Faecal sludge ☐

8. How is wastewater handled before disposal at this place? *(Please tick box (es). Multiple response is possible)*
    a. Is pre-treated ☐
    b. Is not pre-treated ☐

9. In relation to Question 8, option (a) what method of wastewater pre-treatment is used at your facility? *Please tick appropriate box*
    a. Anaerobic pond ☐
    b. Oxidation ditch ☐
    c. Bio-filter ☐
    d. Chlorination ☐
    e. Other (*please specify*) ☐ ______________________________

10. How is wastewater disposed at this facility? (*Please tick box (es). Multiple response is possible*
    a. Piped to the septic tank ☐
    b. Piped to the sewerage system. ☐
    c. Discharged to the storm water drains ☐
    d. Discharged into a surface water body (e.g. river, wetland, pond) ☐
    e. Collect by tankers for disposal at WWTP ☐
    f. Others (*please specify*) ☐

11. How is wastewater generated at this place managed? *(Please tick appropriate box)*
    a. On-site wastewater treatment system (e.g. septic tank, pit latrine) ☐
    b. Off- site wastewater management system (e.g. wastewater treatment plants) ☐
    c. Decentralized wastewater treatment system (e.g. cluster wastewater treatment facilities) ☐
    d. No wastewater management system in existence ☐

PART C: DETERMINING VOLUME OF WASTEWATER RELEASED PER DAY PER LAND USE CATEGORY

12. How many people does this facility accommodate (e.g. staying or working or visiting this facility) per day?

    Number of people accommodated per day ☐

13. Do you have a portable water supply connection to your facility? *Please tick appropriate box*
    a. No ☐
    b. Yes ☐

14. In relation to Question 13, option (a) where do you get water from? *Multiple response possible. Please tick appropriate box(es)*
    a. Borehole ☐
    b. Shallow Well ☐
    c. Communal water selling point (Kiosk) ☐
    d. River ☐
    e. Other (*please specify)* ☐

15. Referring to Question 14, how many buckets of water do you use per day, obtained from the following sources?

a. Borehole ☐

b. Shallow Well ☐

c. Communal water selling point (Kiosk) ☐

d. River ☐

e. Other (*please specify)* ☐

THANK YOU VERY MUCH FOR KINDLY COMPLETING THIS QUESTIONNAIRE.

APPENDIX 2: Research Participant Consent Form

Please tick the box against the term 'yes' or 'no' to agree or disagree in taking part in the research. If you do not understand anything, please ask me or my supervisor (contact details given on the research information sheet)

Id	Consent terms to take part in the research project	Yes	No
1	I confirm that I have read and understand the information sheet dated 31st May 2018 explaining the above research project and I have had the opportunity to ask questions about the project.		
2	I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline.		
3	I give permission for members of the research team (Researcher and Supervisor) to have access to my anonymized responses.		
4	I understand that my name will not be linked with the research materials and I will not be identified or identifiable in the report or reports that result from the research.		
5	I agree to take part in the above research project and will inform the lead researcher should my contact details change		

Name of participant	
Participant's signature	
Date	
Name of Lead Researcher (Person taking consent)	
Signature	
Date	

APPENDIX 3: Distribution of questionnaire respondents by gender and area

Appendix 3.1: Distribution of questionnaire respondents by gender

Gender	Frequency	Percent	Valid Percent	Cumulative Percent
Male	76	41.3	41.3	41.3
Female	108	58.7	58.7	100.0
Total	184	100.0	100.0	141.3

Appendix 3.2: Distribution of questionnaire respondents by area

Study area	Projected Population (2018)	Calculated sample size (minimum)
Nyambadwe	9648	4
Namiwawa	8322	3
Sunny Side	4893	2
BCA	3011	1
Chinyonga	4924	2
Soche East	3830	1
Namiyango	5220	2
Manja	6567	2
Mbayani	84318	31
Mkolokoti	55751	21
Nancholi	3444	1
Misesa	10133	4
Ndirande	178308	66
Chilomoni	24083	9
Manje	1363	1
Chilobwe	17213	6
Total		**156**

APPENDIX 4: Survey Raw Data

Hard copies of original 184 completed questionnaires as well as soft copy of data set in SPSSv20 are available.

APPENDIX 5: Public sewer and surface water standards

General standards for water course (Malawi and WHO) and tolerance limits for Industrial wastewater effluents discharged into public sewers as practiced in Blantyre City (Malawi), Cape Town (South Africa), India (Bhatia, 2003), Nepal and Singapore (Kuyeli, 2008).

No	Parameter	Tolerance limit – Public sewer					Water course	
		Blantyre	Cape Town	India	Nepal	Singapore	MBS	WHO
1	Temperature	40	40	45	45	45	40	45
2	pH	6.5-9.0	5.5-12.0	5.5-9.0	5.5-9.0	6.0-9.0	5-9.5	6.5-8.5
3	BOD_5	400	-	500	400	400	20	-
4	COD	1000	5000	-	1000	600	60	-
5	SS	-	1000	600	600	400	-	-
6	Chloride	-	1500	600	1000	1000	400	250
7	Sulphate	-	1500	-	500	1000	400	250
8	Grease/oil	10	400	100	50	60	-	-
9	Nitrate	-	-	-	50	-	10	50
10	Phosphate	-	25	-	-	-	-	0.5
11	DO	1.0	-	-	-	-	-	-
12	Iron	-	50	-	-	50	0.2	0.3
13	Manganese	-	-	-	-	10	0.1	0.4
14	Cadmium	-	5	2	2	1	0.005	0.003
15	Chromium	-	10	2	2	5	0.1	0.05
16	Copper	-	20	3	3	5	1.0	2.0
17	Lead	-	5	1	0.1	5	0.05	0.01
18	Nickel	-	5	2	3.0	10	0.15	0.02
19	Zinc	-	30	15	5.0	10	5.0	3.0
20	Calcium	-	-	-	-	-	150	-
21	Potassium	-	-	-	-	-	50	-

(Source: Kuyeli, S.M. (2007). *Assessment of industrial effluents and their impact on water quality in streams of Blantyre City, Malawi*. MSc Thesis, Faculty of Science, University of Malawi, Zomba.)

APPENDIX 6: laboratory tests results on water samples from Mudi, Naperi, Limbe and Chirimba Rivers

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NAME OF CLIENT	GEORGE CHIDULO (Msc STUDENT)	**REPORT DATE**	04th December 2018
TESTED BY	Mike Adams / Enock Simumba – Department of Physics & Biochemical Sciences Owen Kapudzama / Ishmael Ng'oma – Department of Civil Engineering		

Laboratory test results for wastewater sampled on 24th November 2018

TEST PARAMETER	UNITS	Limbe River		Chirimba River		Naperi River		Mudi River	
		Inlet	Outlet	Inlet	Outlet	Naperi	Soche	Inlet	Outlet
Temperature	°C	23.2	26.6	-	25.3	25.4	24.9	24.7	19.4
		22.9	27.1	-	25.5	25.2	25.2	24.8	18.9
		24.8	26.4	-	25.0	25.2	25.1	25.3	19.4
pH	pH Units	4.66	5.01	-	4.08	4.08	4.05	4.17	4.12
		4.66	5.01	-	4.08	4.08	4.05	4.17	4.12
		4.66	5.01	-	4.08	4.08	4.05	4.17	4.12
Biochemical Oxygen Demand (BOD_5)	mg/l	23	13	-	193.0	90	68	38	78
		23	12	-	194.8	90	68	37	80
		24	9	-	191.7	90	68	39	79
Chemical Oxygen Demand (COD)	mg/l	58.4	31		372	193	127	90	175
		56.8	27	-	395	188	128	90	168
		57.5	27	-	384	194	136	89	173
Total Suspended Solids	mg/l	<0.001	<0.001	-	1019	<0.001	<0.01	168	11
		<0.001	<0.001	-	1028	<0.001	<0.01	164	16
		<0.001	<0.001	-	1021	<0.001	<0.01	172	12

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Lead (Pb)	mg/l	0.252	0.328	-	1.098	0.728	0.792	0.542	0.481
		0.244	0.346	-	1.070	0.732	0.810	0.547	0.479
		0.233	0.338	-	1.084	0.709	0.794	0.546	0.483
Cadmium (Cd)	mg/l	0.044	0.42	-	0.706	0.013	0.170	0.063	0.078
		0.047	0.48	-	0.741	0.014	0.167	0.084	0.074
		0.044	0.41	-	0.728	0.017	0.158	0.059	0.070
Chromium (Cr)	mg//	0.39	0.19	-	3.32	0.45	0.28	0.36	0.59
		0.49	0.34	-	3.25	0.47	0.18	0.44	0.69
		0.43	0.23	-	3.32	0.51	0.21	0.41	0.60
Total Coliform (Filtration Method)	cfu/100ml	TNTC	TNTC	-	TNTC	TNTC	TNTC	TNTC	TNTC
		TNTC	TNTC	-	TNTC	TNTC	TNTC	TNTC	TNTC
		TNTC	TNTC	-	TNTC	TNTC	TNTC	TNTC	TNTC
Total Colifom (MPN - Colilert Method)	cfu/100ml	97	240	-	1011	62	30	530	152
		94	292	-	1011	57	30	524	152
		98	248	-	1011	58	22	520	152
Faecal Coliform (Filtration Method)	cfu/100ml	TNTC	TNTC	-	TNTC	TNTC	TNTC	TNTC	TNTC
		TNTC	TNTC	-	TNTC	TNTC	TNTC	TNTC	TNTC
		TNTC	TNTC	-	TNTC	TNTC	TNTC	TNTC	TNTC
Faecal Colifom (MPN - Colilert Method)	cfu/100ml	5	30	-	225	15	3	30	2
		5	33	-	218	15	3	38	2
		5	28	-	242	15	3	28	2

NOTE

- The results listed refer only to the tested sample and applicable parameters
- In case of dispute our liability is limited to the sampled/received samples
- Samples will be preserved for 2 weeks on request
- According to the method used, values for coliform bacterial have to be multiplied by 1000 (dilution factor). 0.1ml of sample was diluted in 99.9ml of distilled water.

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KEY

- MPN = Most Probable Number
- NTU = Nephelometric Turbidity Units (Equivalent to FNU)
- FNU = Formazin Nephelometric Units
- TNTC = Too Numerous To Count
- cfu = Colony Forming Units

1.0 mg/l = 1.0 ppm = 1.0 g/m³