

**ASSESSMENT OF INDUSTRIAL EFFLUENTS AND THEIR IMPACT ON
WATER QUALITY IN STREAMS OF BLANTYRE CITY, MALAWI.**

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the Degree of Master of Science in Environmental Sciences, at Chancellor College,
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DECLARATION

I, **Stephen Massah Kuyeli**, declare that this is my own work and has not been presented or submitted elsewhere for any award. All additional sources of information have been acknowledged.

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We hereby declare that this thesis is the student's original work and where assistance has been sought, this has been acknowledged. It is therefore submitted with our approval.

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DEDICATION

This thesis is dedicated to my wife Treza and children (Joy, Shalom and Stephen). Your endurance was not in vain. God will surely honour it in due time.

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ABSTRACT

The physicochemical characteristics of effluents from industries, wastewater treatment plants as well as stream water in Blantyre city were assessed in order to determine their impact on water quality of streams near industrial activities. The effluents and stream water at selected points were analysed for dissolved oxygen, pH, alkalinity, electrical conductivity, temperature, suspended solids, oil and grease, biochemical oxygen demand, chemical oxygen demand, chlorides, sulphates, nitrates, phosphates, and the metal ions (Ca, K, Pb, Mn, Ni, Cd, Zn, Fe, Cu, and Cr).

The results showed that effluent quality discharged by the twenty eight industries in Blantyre, Malawi, varied greatly in both composition and potential to pollute the natural environment. The mean levels of sulphates, nitrates, phosphate, biochemical oxygen demand, suspended solids, electrical conductivity, alkalinity, cadmium, nickel, lead, chromium, copper, iron calcium and potassium in the industrial effluents differed significantly between the seasons ($p < 0.05$) whereas the levels of chlorides, chemical oxygen demand, dissolved oxygen, temperature, pH, zinc, oils and grease did not differ significantly in both seasons ($p > 0.05$). However, levels of chlorides, cadmium, copper, iron and nickel were below the public sewer discharge limits set by Blantyre City Assembly, Cape Town, Nepal, Singapore and India, while levels of chromium (56.12 mg/l), zinc (30.83 mg/l), lead (2.60 mg/l), Biochemical Oxygen Demand (1570.32 mg/l), Chemical Oxygen Demand (26784.33 mg/l), oil and grease (650.00 mg/l) were observed to exceed the public sewer discharge limits in some of the industries.

Assessment of efficiency of pretreatment plants in industries revealed that the overall order of efficiency of treatment plants in removing pollutants was as follows; $BOD > SS, O\&G > COD > Cl^- > PO_4^{3-}, Alkalinity > SO_4^{2-} > EC > NO_3^-$. For metals the best efficiency was observed at an oil interceptor treatment system where removal percent ranged from 7.24% for manganese to 100% for Copper.

In the major wastewater treatment plants being managed by the local authority the efficiency for metals varied from 0.51% for calcium to 100% for zinc and copper. Removal efficiencies for the other parameters ranged from 4.02 % for chlorides to 97.55 % for oil and grease. However, some parameters like chlorides, sulphates, phosphates, nitrates and few metals (Zn, Cu, Mn) survived the treatment systems indicating the possibility of pollutants passing through the treatment system without being reduced and some increasing in the process.

Characterization of the wastewater at the major treatment plants revealed that metals such as lead, cadmium, nickel were conspicuously absent whilst other metals were sparse. The presence of COD, BOD and suspended solids was detected in all the wastewater treatment plants.

The water characteristics of streams passing through the industrial areas showed that the impairment of water quality depended on the type of industry in its vicinity and state of sewerlines which conduits the wastewater from the source to the designated Blantyre City Assembly wastewater treatment plants. Most of the parameters such as pH, conductivity, chlorides, sulphates, temperature, Oil and grease, calcium and potassium were below the acceptable limits set by Malawi Bureau of Standards and World Health Organization for surface water meant for drinking. However the levels of phosphates, nitrates, COD, BOD and cadmium were observed to exceed the limits set by the regulatory bodies.

It was generally observed that the effluents from industries in Blantyre City have a high potential of polluting the water bodies and if they are not properly managed by good wastewater treatment systems, they could result into gross impairment of water quality of streams in Blantyre City. It was therefore suggested that Blantyre city Assembly and other environmental regulatory bodies such as Environmental Affairs Department, Water Resources Board, should be more aggressive and effective in environmental monitoring, assessment and enforcement of environmental laws and regulations so as to preserve the water resource from further degradation. Further more, it is recommended that effluents from industries should be treated to acceptable levels by the industries before discharging to either rivers or sewerlines.

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ACRONYMS

AAS	Atomic Absorption Spectrophotometer
AGOA	African Growth and Opportunity Act
AOAC	Association of the Official Analytical Chemists
BCA	Blantyre City Assembly
BSR	Business for Social Responsibility
CACWTRF	City of American Canyon Wastewater Treatment and Reclamation Facility
CWQG	Canadian Water Quality Guidelines
DEPA	Danish Environment Protection Agency
EAD	Environmental Affairs Department
EHD	Environmental Health Directorate
ETPI	Environment Technology Partnership Initiative
FCEAD	Forsyth County Environmental Affairs Department
GEO	Global Environment Outlook
ILO	International Labour Organisation
IMERCSA	Musokotwane Environment Research Centre for Southern Africa
MBS	Malawi Bureau of Standards
NGRC	Northern Georgia Regional Development Centre
PIP	Population Information Programme
SOER	State of Environment Report
UNEP	United Nation Environment Programme
US-EPA	United States-Environment Protection Agency
UNIDO	United Nations Industrial Development Organisation
UNDP	United Nations Development Programme
WWAP	World Water Assessment Programme
WHO	World Health Organisation
WWTP	Wastewater Treatment Plant

CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW

1.1 BACKGROUND

The continuing increase in global population is putting unprecedented demand on freshwater supply because clean water is essential to the health and well being of humans and their environment (Carani, 2005). Over the years there has been great demand for this natural resource to the extent that global freshwater consumption rose six fold between 1900 and 1995 at more than twice the rate of population growth (GEO, 2000). However, the availability of freshwater is under threat due to lack of proper sanitation and waste treatment facilities, and factors associated with socioeconomic development such as industrial activities, agriculture, constructions of various forms (Peters and Meybeck, 2000).

While the percentage of people served with improved water supplies worldwide increased from 4.1 billion in 1990 to 4.9 billion in 2000, 1.1 billion people still lack access to safe drinking water and 2.4 billion lack access to improved sanitation and most of these people are in Africa and Asia. Lack of access to safe water supply and sanitation results in hundreds of millions of cases of water-related diseases, and more than 5 million deaths every year (UNEP, 2002). The inadequate sanitation services include poor management of both industrial and domestic waste, which have a potential to degrade water quality.

The growing increase in socio-economic activities worldwide has been accompanied by an even faster growth in pollution stress on the aquatic environment (UNESCO/WHO/UNEP, 1992). Pollutants are being released continually into the water environment, both directly and indirectly by a range of different types of agriculture, industries from oil refineries to pharmaceutical plants, and untreated wastewater from other sectors, impacting both the quantity and quality of available water (WWAP, 2006). The situation is more critical in developing countries where well-treated clean water supply is inadequate and people depend on streams, rivers, wells and boreholes for drinking water with little or no treatment. Despite the inadequacy of water supply, the management and conservation of the available water bodies is generally poor thereby posing a risk to the users of outbreaks of epidemics such as cholera and other water related diseases (Fakayode, 2005).

In developing countries, on average 90% to 95% of all domestic sewage and 75% of all industrial waste are discharged into surface water without treatment of any kind (PIP, 1998) and although industry is a small user of water in terms of quantity, it has a significant impact on quality. Over three-quarters of fresh water drawn by the domestic and industrial sectors return as domestic sewage and industrial effluents which inevitably end up in surface water contributing to water quality degradation worldwide (Mukherjee et al, 2006). In essence, a principal cause of water scarcity is water quality degradation, which can critically reduce the amount of freshwater available for potable, agricultural, and industrial use. Thus, the quantity of available freshwater is closely linked to the quality of the water, which may limit its use (Peters and Meybeck, 2000).

The major water quality issues resulting in degradation include water-borne pathogens and noxious and toxic pollutants. Despite the efforts of United Nations organizations, international banks, and some national governments over the past several decades to protect water resources, human health and aquatic life continues to be at risk due to water quality problems in many parts of the world (World Resources Institute, 1996; Peters and Meybeck, 2000). Some authorities like United Nations and International Joint Commission have predicted that if the situation goes unchecked water quality degradation may result in hydrocide for future populations (Enger and Smith, 2002).

Africa as a continent is facing increasing water pollution and degradation and there is a growing recognition of the need to deploy urgent action in order to save the rich natural environment of Africa from the environmental decline it has experienced in the past three decades (UNEP, 2002). Most of the African countries are trying to adopt the approaches that have been used in the developed countries in order to save their natural resource like water from degradation. Some of the pollution control approaches include polluters pay principle and cleaner production methods.

Malawi is one of the African countries that is generally rich in water resources, which are stocked in its lakes, rivers and aquifers (DREA, 1994) and government policy emphasizes conservation and protection of the resources. However, although commendable progress has been made in the development of water resources, there are still environmental issues that the country should address as a matter of urgency in order to conserve water resources from depletion and degradation. According to UNEP report (2002) Malawi falls within the region of

countries experiencing water stress (Figure 1.1). Factors that have contributed greatly to the depletion and degradation of water resources in Malawi include poor management of catchment areas, environmentally unfriendly agricultural practices, rapid population growth, inappropriate discharge of industrial wastes and the weak institutional structures for enforcing the Water Resources Act (Malawi State of Environment report, 2002).

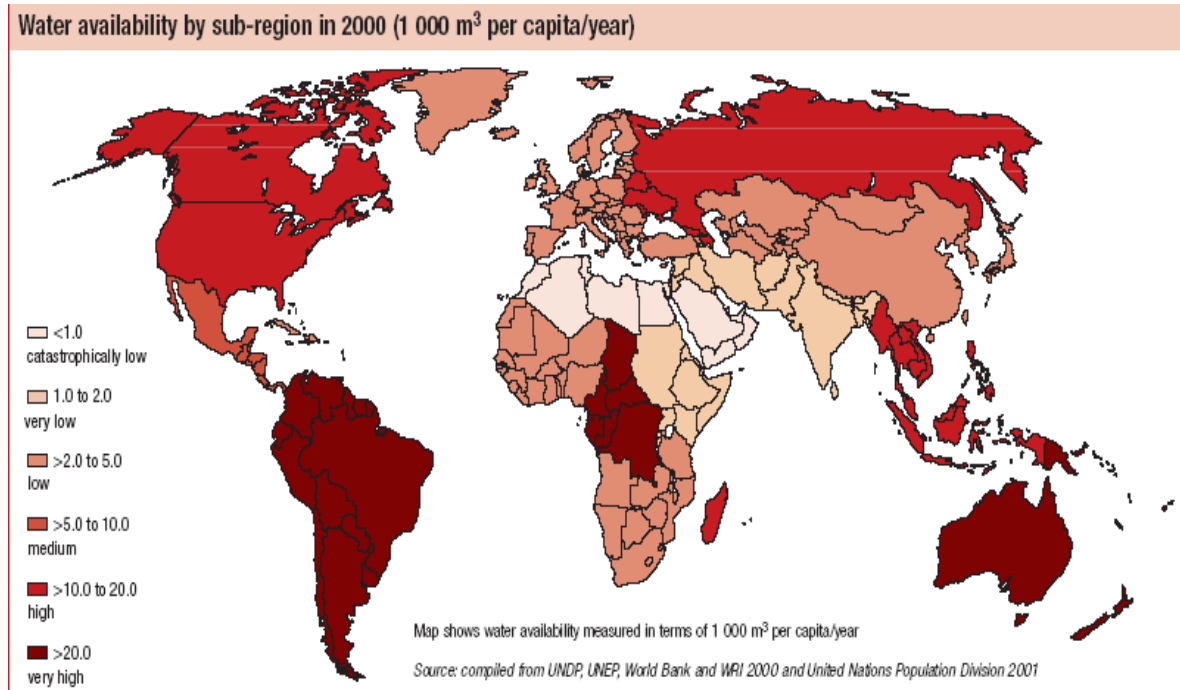


Figure 1.1: World map showing water availability

1.2 INDUSTRIAL EFFLUENT: A THREAT TO WATER QUALITY

Malawi, like other African countries, is experiencing industrial growth which is making environmental conservation a difficult task (Kadongola, 1997; Phiri et al, 2005). One of the pronounced causative forces of the water quality degradation is the poor treatment of industrial waste produced by several industries. Malawi is predominantly an agrarian economy, but recent years have seen considerable industrial development in and around the major cities and, in particular Blantyre, which is the country's major industrial and commercial centre since the establishment of the African Lakes Corporation in 1878 (BCA Master Plan Study, 2000).The development of industries within the city continues to date as evidenced by rapid growth of textile industries due to the African Growth and Opportunity Act (AGOA) which provides easy

access for the textile products to United States of America markets. More than three industries have come into existence namely, Chirimba garments, Crown Fashion and Limbe textile company adding up to the already existing giant Mapeto David Whitehead textile and knitwear company. All the textile companies are largely involved in sewing garments except Mapeto David whitehead which makes both fabric and garments.

Blantyre City has recently witnessed the expansion of the paint industry with the advent of Monolux and Plascon paints companies. Further, Optichem Malawi Ltd, one of the fertilizer manufacturing companies in Blantyre has expanded its production in fertilizers so as to boost the agricultural production of Malawian farmers. Industries involved in producing beverages, milk products and chemicals are also increasing their production in order to meet the market demands (BCA, 2005). Such economic strides are a positive development for Malawi as a nation. The challenge however arises because most industries are emphasising production without necessarily considering the environment into which the effluents generated from their process water are being discharged and yet industries are considered to be the primary source of pollution in the Zambezi basin, producing huge amounts of liquid effluent that often find their way into water bodies (IMERCSA, 2004). According to United Nations Industrial Development Organization 2004 report, the textile sector is reputed to account for approximately 11 percent of industrial organic water pollution in Sub Sahara Africa (Figure 1.2). The other categories of industries also contribute significantly to industrial water pollution (World Bank, 2002; UNIDO, 2004).

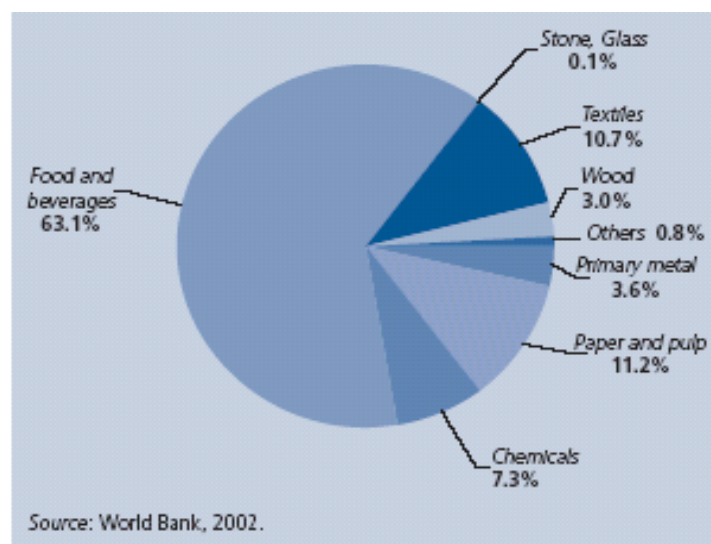


Figure 1.2: Distribution of organic pollutant effluent across industrial sector in Sub Sahara Africa in 1999.

Industrial pollution is considered one of the major issues in environmental protection. Based on the type of industry, various levels of pollutants can be discharged into environment directly or indirectly through public sewer lines (Emongor and Nkegbe, 2005). This problem is also present in Malawi where some industries within Blantyre discharge their industrial effluent either directly into the sewer lines or the neighbouring water bodies without prior treatment; a few pretreat their effluent before discharge into the public sewer.

The discharge of poor quality effluents especially by industries into the municipal wastewater treatment plants reduces the performance of these treatment facilities over time due to hydraulic overloading and corrosion of the sewer pipe system (Nyoni, 1999; Ikhu-Omoregbe, 2001). Further, pollutants from industrial effluent impair the quality of the natural ecological balance thereby curtailing natural utility and exerting a deleterious effect on life (Emongor et al, 2005). Effluent discharges into receiving waters and the cumulative hazardous effects on the environment have become increasingly important due to rapid industrialization in modern society (Ezeronye and Ubalula, 2004). Water bodies are constantly used as receptacles for the untreated waste water or poorly treated effluents accruing from industrial activities, which has rendered many water bodies unsuitable for both primary or secondary usage (Fakayode, 2005).

Degradation of the water quality is defined as the unfavourable alteration of the physical, chemical and the biological properties of water that prevents its domestic, commercial, industrial, agricultural, and recreational and other beneficial uses (Bhatia, 2003). The Malawi State of Environment report, 2002 revealed that the quality of water in Mudi River in Blantyre is degraded largely due to industrial activities. For example, Lakudzala et al (1999) reported iron concentrations of up to 1.86 mg/L in Mudi River and lead concentrations of up to 1.0 mg/L in Likhubula River. The recent water quality inventory of Blantyre streams by Sajidu *et al*, 2006, revealed levels of lead from 0.027 to 0.118 mg/L, cadmium from 0.002 to 0.015 mg/L, zinc from 0.166 to 0.630 mg/L with most values exceeding the acceptable limits. The continuous monthly monitoring of the streams being done by Blantyre City Assembly shows high levels of BOD as high as 40mg/l against the recommended 20 mg/l standard set by both Malawi Bureau of Standards and World Health Organization (BCA report, 2005).

Water resource degradation in Blantyre affects a large area in Malawi because most of the rivers in Blantyre that host industries along their banks join major rivers which are themselves tributaries to Shire river which is the main river in Malawi. According to a human

development report released by United Nations Development Programme (UNDP), 4 million Malawians, which is a third of the population, do not have access to safe water because they use contaminated stream water (UNDP Report, 2006). The situation requires concerted efforts by several stakeholders to ensure that the water resource is protected from further degradation by managing the upstream activities. The degradation of water quality in upstream parts of a watershed can have negative effects on downstream users, and because there is generally a continuum of users throughout a watershed, the degradation effects cascade through the watershed (Peters and Maybeck, 2000).). As the rivers flow from Blantyre city, people downstream of Blantyre city use the same water for domestic purposes or irrigating their gardens.

1.3 WATER POLLUTION INCIDENCES FROM OTHER COUNTRIES

It is well known that in most developing countries, industries dispose of their effluents without adequate characterization, quantification and pre-treatment due to economic and technological constraints (Sweeney, 1995; Ikhu-Omoregbe, 2005 et al). These are the effluents that eventually end up in the streams and cause the reported high levels of pollution. Municipal and industrial wastewaters are largely being discharged without treatment into surface receiving waters in both the developed and developing world and examples of gross pollution are ubiquitous (Feacham et al, 1977). The observation made by Feachaman et al is exemplified by both present and old incidences of pollution as evidenced by the examples highlighted below.

In Lesotho, the textile factories collectively use approximately 12 million litres of water per day, of which approximately 15% is lost to evaporation and spillage within the factories themselves. The remaining water is used for processing and eventually released as effluent, which is reported to have created a deep blue river with high levels of chemical oxygen demand. As a result, the Caledon River has become one of the most turbid rivers in Southern Africa, and future growth of the textile industry is expected to increase the proportion of sediment and sludge in the river by about 20 percent. (World Bank, 2002, UNIDO, 2004).

The Itai-Itai epidemics in Japan remain a classic example how industrial effluent can be a threat to public health. In the 1950-60s in Japan, farmers in a town called Haginoshima watered their rice fields with water contaminated by cadmium from effluent emanating from

local industries. The rice absorbed the cadmium and when eaten, it caused the consumer's bones to weaken and break easily. The whole body became sore and light, touching was even painful. At least 100 people died. It was called Itai-Itai disease, 'itai' being the Japanese word meaning 'touch' (Masanori, 1998).

Over three quarters of China's 50, 000 kilometres of major rivers are heavily polluted and filled with pollution and sediment that they no longer support fish life (PIP, 1998). In 1992 China industries discharged 36 billion metric tonnes of untreated or partially treated effluents into rivers, streams and coastal waters. In 1986, along sections of the Liao River, which flows through a heavily industrialized part of the northern China, almost every aquatic organism within 100 kilometers was killed when over one billion tons of industrial wastes were dumped (PIP, 1998).

Industries in Alexandria account for around 40% of all Egypt's industrial output, and most discharge untreated liquid wastes into the sea or into Lake Maryut. In the past decade, fish production in Lake Maryut declined by some 80% because of the direct discharge of industrial and domestic effluents. The lake has also ceased to be a prime recreational site because of its poor condition (ILO, 2000)

A study of 15 Japanese cities showed that 30 per cent of all groundwater supplies are contaminated by chlorinated solvents from industry; in some cases, the solvents from spills travelled as far as 10 km from the source of pollution (UNEP 1996).

The Tiete River in Brazil, which passes through Greater Sao Paulo, one of the world's largest urban agglomerations, receives 300 tonnes of effluents each day from 1,200 industries located in the region. Lead, cadmium and other heavy metals are among the main pollutants. It also receives 900 tonnes of sewage each day, of which only 12.5% is treated by the five sewage treatment stations located in the area (Hardoy and Satterthwaite, 1989).

The Lyari river, which runs through Karachi, Pakistan's largest industrial city, is an open drain from both the chemical and the microbiological point of view, a mixture of raw sewage and untreated industrial effluents. Most industrial effluents come from an industrial estate with some 300 major industries and almost three times as many small units. Three-fifths of the units

are textile mills. Most other industries in Karachi also discharge untreated effluents into the nearest water body thereby making the water unsuitable for any primary use (ILO, 2000).

In Bangladesh, water of the river Balu is badly contaminated by urban and industrial wastes from Tongi and the effluent flowing out through the Begubari Khal, most of which emanates from the Tejgaon industrial area in Dhaka. In the rivers of Balu and Turag, water quality in the dry season becomes worse, with DO concentrations becoming almost zero (Bangladesh SOER, 2001).

In many developing countries, rivers downstream of large cities are highly polluted. For example levels of suspended solids in Asia's rivers have almost quadrupled since the late 1970s and rivers typically contain four times the world average and 20 times above safe levels. The faecal coliform count in Asia's rivers is 50 times higher than the WHO guidelines. People using such water for washing, bathing or drinking are at high risk (GEO, 2000).

In southern Africa factories and industries are reported to be discharging effluents directly into the rivers or the ocean. The industries include textile factories, battery factories, fertilizer plants, tanneries and pulp mills. Effluents from these industries contain poisons harmful to plants and fish in the water, and to people and animals using that water. Supporting the allegation, a factory inspector in Botswana reported that the pollution of the Peleng River with industrial effluents had escalated to the extent that fish died and the borehole which used to supply drinking water to Peleng village had to be closed (IMERCSA, 2005).

1.4 EFFLUENT QUALITY MONITORING: INDUSTRIES IN BLANTYRE, MALAWI

In recent years, a number of environmental pollution incidents, from both within and outside Malawi, have led to a renewed drive to monitor and control the quality and quantity of liquid effluents being discharged especially by industries into the municipal treatment systems and natural watercourses in Blantyre.

The Department of Environmental Affairs and the Water Resources Board are mandated by both Environment Management Act (EMA 1996) and the Water act to inspect premises of commercial institutions to determine if any of the activities carried out within their operation

yard are impacting negatively on the environment. The jurisdiction of their power extends to monitoring the water quality of streams which is done occasionally.

The local authorities through the Local Government Act and their respective bylaws are empowered to monitor trade premises which include industrial areas. The ability of a particular local authority to execute its powers as enshrined in the acts and bylaws hinges on the availability of resources within the organization. This is the reason why some local authorities are more active in environmental monitoring than others. Blantyre City Assembly stands out as a good model in this matter (BCA, 2005). The local authority in Blantyre carries out routine monitoring to determine the quality of effluent emanating from industries in Blantyre on few selected companies. However, the most emphasized parameter is Biochemical Oxygen Demand and yet industrial pollution may be microbiological, physical, organic and inorganic and hence a wide range of parameters needs to be monitored (Harrington and Alibhai, 1995). The impact of industrial discharge depends not only on its collective characteristics such as biological oxygen demand (BOD) and suspended solids, but also on its content of specific inorganic substances (<http://www.arij.org/pub/index.htm>). There is therefore the need to characterize and quantify the industrial effluent pollution load thereby generating reliable data for planning and cleaner production practices for both industries and the local authority in Blantyre city.

1.5 INDUSTRIAL EFFLUENT GENERATION AND COMPOSITION

Water pollution is most commonly associated with discharge of effluents from sewers, drains and in factories to the water body of the river (Rashed, 2005). The effluents result from spent wastewater from manufacturing processes. Manufacturing and industrial plants utilize water in three ways: as a process material, as a heat exchange medium and to remove dirt or impurities from a product in industries (Porteous et al., 2000). Some of the water is recycled whilst some is discharged as effluent.

Effluent from manufacturing plants may contain organic and inorganic material. This material may be in suspension or in solution. Most effluents vary in their strength and composition, on seasonal diurnal or hourly basis due to variations in the quality of the raw materials, or changes in specification of the finished product. Many industrial processes are batch rather than continuous processes so that some effluent discharges will be intermittent rather than

continuous (Thinkquest, 2002). Wastewaters from industrial processes differ in their strengths or potential for polluting rivers. The pollution strengths of effluents from various trades and industrial process are compared in table 1 in terms of BOD, pH and suspended solids.

Table 1.1: Comparative strengths of liquid wastes

Source of waste	5-day BOD mg/l	pH	Suspended Solids mg/l
Domestic sewage	250-300	6-8	250
Wool scouring	2000-5000	9-11	3000-30000
Laundry	1600	8-9	250-500
Textile	700-1000	5-12	6000
Brewery	850	4-6	90
Dairy	600-1000	Acid	200-400
Abattoir	1500-2500	7	800
Potato processing	2000	11-13	2500
Oil refinery	100-500	2-6	130-600
Paint	100-500	8-13	2800-3800

Adopted from Porteous, 2000

Generally, industries processing food generate large volumes of effluent containing natural organic compounds such as carbohydrates, proteins and fats, while industries producing chemicals often generate low volume but highly toxic waste streams.

Abattoirs generally use large quantities of water for washing meat and cleaning processing areas (EPA, 2001). Most water consumed at abattoirs ultimately becomes effluent. Abattoir effluent contains high levels of organic matter due to the presence of manure, blood and fat. It can also contain high levels of salt, phosphates and nitrates. The most significant contributor to the organic load is blood, followed by fat. Blood is also the major contributor to the nitrogen content of the effluent stream. Salt and phosphorus originate from the presence of manure and stomach contents in the effluent. At those plants where rendering occurs, the effluent from rendering typically represents the single most significant source of pollutant load in abattoir effluent (UNEP and DEPA, 1998).

The textile industry is distinguished by the raw material used and this determines the volume of water required for production as well as wastewater generated. In the production, slashing, bleaching, mercerizing, and dyeing are the major consumption activities as well as wastewater generation. The nature of the processing exerts a strong influence on the potential impacts

associated with textile manufacturing operations due to the different characteristics associated with these effluents (Yusuff and Sonibare, 2004). Some of the crucial pollution parameters in textile wastewater effluent include suspended solids, BOD, COD, Nitrogen, phosphate and heavy metals like chromium, lead, zinc and copper to wastewater (EPA, 1974; Yusuf et al., 2004).

The main source of process wastewater in any paint industry is the manufacturing of water-based paint. Usually the plant is equipped with mixing-machines including dispersers and kneaders and wastewater is generated due to washing of these machines. Wastewater generated from paint industries mostly has a basic pH and consists of TSS, TDS and settleable solids as pollutants besides the fact that the aggregate organic pollution indicated by COD and BOD are equally high. Wastewater generated by pigment manufacturing process usually contains high levels of heavy metals, such as Lead and Chromium (ETPI, 2000). In a study of paint industries in Pakistan the levels of lead in the effluent were recorded as high as 2.0ppm, levels observed to be higher than regulatory requirement (ETPI, 2000). The level of pollution also varies from unit to unit, depending mainly on the type of process and the size of the industry.

In pharmaceutical industries wastewater is mainly generated through the washing of the equipment, workers hands and spillages from the products (Changa P, 2006). Though the wastewater discharged is small in volume; it is highly polluted, because of presence of substantial amounts of organic pollutants (Overcash, 1986; Imran 2004). World Bank Pollution Abatement handbook (1998) lists arsenic, copper, and zinc as some of the pollutants associated with pharmaceutical effluent, which may result from use of these metals in small quantities as vital constituents of drugs.

Pollutants in industrial effluent are not limited to a specific industry but they can be traced in any industry depending on the industrial activities. For example, cadmium is generated in waste streams from pigment works, textiles, electroplating and chemical plants. Chromium is present in the wastewaters of plating operations aluminium anodising, paint and dye operations. Lead is commonly detected in industrial effluents arising from battery manufacture, printing, painting, dyeing and matches (Bhatia, 2003). Oil wastewater emanates from industrial effluents from garages, oil refineries, storage tanks, automobile waste oil and petrochemical plants. Phosphates being a common raw material in detergents can be traced in industrial effluent as a result of being used for cleaning equipments and machinery.

Nitrate is used extensively in the production of fertilizers because of its property of being readily absorbed by plants for growth. Nitrate is also used in a variety of industrial applications, including as oxidizing agents in explosives, matches and pyrotechnics. Other uses are in photography, glass making, engraving, textile dyes, food preservatives, and as a raw material for manufacturing nitric acid (CWQG, 2005). Thus the effluents from these plants are likely to contain nitrates.

1.6 IMPACT OF WATER POLLUTANTS ON THE ENVIRONMENT

The effects of water pollution are not only devastating to people but also to animals, fish, and birds. Polluted water is unsuitable for drinking, recreation, agriculture, and industry. It diminishes the aesthetic quality of lakes and rivers. More seriously, contaminated water destroys aquatic life and reduces its reproductive ability. Eventually, it is a hazard to human health. The following section therefore highlights the effect of these water pollutants on different parts of the environment.

1.6.1 Sewer and Wastewater Treatment

It is a common practice of most local government authorities to set discharge limits on industrial effluents to water bodies and sewerlines. The ultimate goal is to reduce the pollution load from posing adverse effects on the sewer, streams and human beings. Some of the limits set total prohibition to the discharges in order to avoid danger to sewer men, obstruction to flow, damage to sewer structures or interferences with waste treatment processes (Bridgewater and Mumford, 1979).

Obstruction to flow may arise from blockage due to grease, deposition of suspended solids or the trapping of floating materials such as papers. Very hot industrial effluents are not only a hazard to the sewer men but they also accelerate chemical degradation and the production of noxious gases while low (acidic) pH causes corrosion in sewers systems and increases the release of toxic and foul smelling hydrogen sulphide gas. This gas has been responsible for the deaths of numerous sewer workers (Italocorotondo, 2005). Sulphates are converted either into sulphuric acid, which accelerates corrosion, or into sulphides, which produces odour nuisances. This is why a permissible pH range is usually specified and sulphates and sulphides are limited (Bhatia, 2003). The conversion of sulphate to sulphide is due to reducing bacteria and sulphur bacteria present in the system (Bhatia, 2003).

Effluent is channelled to the treatment plant through sanitary conduits popularly known as sewerlines. Heavily polluted effluents have the potential to interrupt the treatment system because all sewage plants incorporate a biological oxidation unit, usually of the activated sludge or percolating filter type. The living organisms involved in these processes can only operate within fairly narrow limits of pH, nutrients, temperature and chemical conditions. Any waste, which alters these conditions, for example biochemical poisons may retard or inhibit completely these treatment processes (Bridgewater and Mumford, 1979). For example, toxic metal ions like copper, chromium, and zinc interfere with biological oxidation by tying up enzymes required to oxidize organic matter (Bhatia, 2003). Since most of these metals are not removed by biological treatment they are liable to pass into the surface waters receiving the discharge of final effluent (Bridgewater, 1979)

Biochemical Oxygen Demand is usually exerted by dissolved and colloidal organic matter and imposes a load on the biological units of the treatment plant. An increase in organic waste results in more bacterial activity that requires more oxygen leading to an added BOD load and, consequently, greater biological unit capacity for its treatment. This calls for an increase in both capital outlay and daily operating expense (Bhatia 2003).

1.6.2 Aquatic and Human Health

When a potentially polluting effluent is released into a stream, there follows a sequence of events in time and distance depending on among other factors the nature of the pollutant and this sequence leads to different environmental consequences (Porteous, 2000). In the presence of favorable abiotic factors like temperature, pH, sunlight, a little over 0.01 mg/l phosphate and 0.1 mg/l nitrate speed microorganism growth and thereby accelerate eutrophication of natural waters (Matsuo et al 2001; Emongor et al, 2005). As reported in the Johns Hopkins school of health on pollution problems and population, in 1980, 48% of lakes and rivers in the United States of America exceeded the 0.1mg/l phosphate standard to prevent the growth of nuisance plant due to eutrophication because at even a small concentration of 0.025mg/l phosphate still results in plant growth. Nitrogen and phosphorous are the major causes of eutrophication. Eutrophication affects the aesthetics on streams and results in odour and algal bloom. It is also reported that algae can be toxic to cattle and it affects taste of water (Fatoki and Muyima, 2001).

The trend of increasing nitrate levels in rivers and groundwater water is causing concern due to its grave health risk to human or animal consumers (Porteous, 2000). The human health risk associated with consumption of water containing high nitrate concentrations ($>10\text{mg/l}$) is due to the reduction of nitrate to nitrite in the human gut, which causes conversion of the oxygen carrying haemoglobin in the blood to an inert form known as methaemoglobin (Bolger and Stevens, 1999). The altered blood cells can no longer carry oxygen, which can result in brain damage or suffocation, the condition known as methaemoglobinaemia (blue baby syndrome). It is reported that drinking water with nitrate concentrations above 50mg/l can cause adverse health effects in infants less than three months of age and nitrate concentrations above 100mg/l can affect pregnant women and those adults with a rare metabolic condition called congenital glucose-6-phosphate dehydrogenase deficiency which is defined as an inability to metabolise sugar (EHD, 2006). Infants under the age of three months are particularly susceptible to nitrite induced methamoglobinaemia because their stomach acid is not strong enough to stop the growth of bacteria that convert nitrate to nitrite (EHD, 2006) Consumption of drinking water containing elevated concentrations of nitrate reportedly caused the death of an infant in South Dakota, USA (Johnson *et al.*, 1987, Bolger et al, 1999).

The pH of water affects solubility of many toxic and nutritive chemicals; therefore the availability of these substances to organisms is affected. As acidity increases most metals become more water-soluble thereby becoming available for uptake by aquatic life including microbes. This has the effect of retarding microbial activity in the water systems thereby reducing decomposition and nutrient cycling. If the pH of water increases, the presence of ammonia poses a problem because ammonia becomes predominant and toxic with slight increase in pH because increases of pH to levels above 9.0 will reduce the ionization of ammonia to ammonium, which is its non-toxic form (FCEAD, 2005).

Dissolved Oxygen is a very important indicator of a water body's ability to support aquatic life. Fish and other aquatic animals depend on dissolved oxygen to live. Oxygen less than 4mg/l in aquatic environment can cause hypoxia. However the amount of dissolved oxygen in streams is dependent on the water temperature, the quantity of sediment in the stream, and the amount of oxygen taken out of the system by respiring and decaying organisms (NGRDC, 2006). Higher levels of these parameters changes the chemistry of the water bodies thereby rendering the water bodies non supportive to the aquatic life.

Heavy metals and other toxic compounds present in the effluent may pose considerable health risks to the population using such contaminated water. Metals are unique environmental and industrial pollutants in that they are found naturally distributed in all the phases of the environment. Through industrial processes metals are concentrated and transformed into various products (Orisakwe et al, 2004). These processes often lead to much higher concentrations of different chemicals than those naturally present in the environment. The discharge of wastewater containing the concentrated metals can become part of the various food chains in the ecosystem and contamination of that kind is a significant stage of a sequence of events beginning with the discharge of a contaminant and its subsequent movement through various levels of the environment (Fatoki and Mathabatha, 2001).

Many metals and metalloids are essential for the normal growth, development and reproduction of organisms. These include not only abundant elements (essential macronutrients) such as calcium, magnesium, potassium, and sodium, but also trace elements (essential micronutrients) such as chromium, copper, iron, manganese, nickel, and zinc. Elements such as copper, iron and manganese can exist in more than one oxidation state in cells (e.g., Fe (II) versus Fe (III)) and can catalyze essential life processes that involve electron transfer in processes like photosynthesis, respiration, and nitrogen fixation (Chapman and Wang, 2005). Elements such as nickel and zinc do not readily undergo oxidation state changes but can catalyze essential life processes that involve hydrolytic transformation (e.g., hydration and dehydration of carbon dioxide) (Stumm and Morgan, 1996; Butler, 1998). Interest in the metals like zinc, copper, iron and manganese, which are required for metabolic activity in organisms, lies in the narrow 'window' between their essentiality and toxicity (Peerzada et al, 1990). All essential metals can become toxic when their concentration becomes excessive. Usually this happens when levels exceed by 40 to 200 fold those required for correct nutritional response (italocorotondo, 2005). Figure1.3 shows the graph of fine lines demarcating the optimal and excess levels of essential metals.

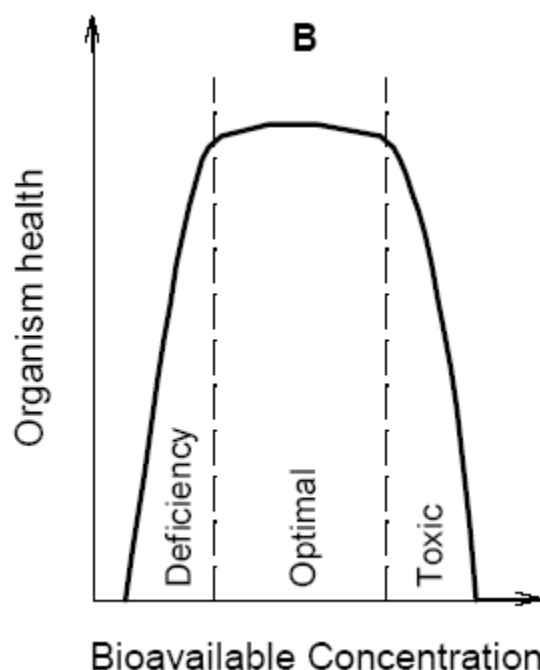


Figure 1.3: Graph showing essentiality and toxicity of essential metals

Source: Peter M. Chapman and Feiyue Wang, 2005.

The essentiality of these metals and metalloids results in a bell-shaped dose-response curve, with deficiency symptoms occurring at low concentrations and toxic effects occurring at high concentrations (Figure 1.3). Between the two extremes there is generally an optimal concentration range within which an organism experiences optimal growth, development and reproduction. When the environmental concentration of an essential element is within the optimal concentration range, organisms can regulate their internal concentrations of the element through binding and detoxification by metallothioneins in animals and bacteria (Roesijadi, 1992) or phytochelatins in algae, plants, and some fungi (Grill, Winnacker & Zenk, 1985; Ahner and Morel, 1995). However at elevated concentrations when the influx of metals and metalloids exceeds the regulation (for essential elements) toxic effects may occur (Chapman and Wang 2005)

For example, excess manganese in the diet prevents the use of iron in the regeneration of blood hemoglobin as consequently large doses of manganese can cause apathy, irritability, headaches, insomnia and weakness of legs. Psychological symptoms may also develop including impulsive acts, absent mindedness, hallucinations, aggressiveness and unaccountable laughter. Finally a condition similar to Parkinson's may develop (Italocorotondo, 2005).

Iron and manganese in combination with natural or man-made organic compounds can cause staining problems. Organic compounds like phenol react with iron and manganese to form very stable and difficult to remove darkly coloured materials. In addition to staining problems, large amounts of these metals can influence the taste of water (Italocorotondo, 2005)

Metals considered as non essential elements like Cd, Hg, Cr, Pb may exhibit extreme toxicity even at low levels under certain conditions, thus necessitating regular monitoring to enable interventions before their presence affects the environment. (Fatoki et al, 2001). Recent data indicate that adverse health effects of cadmium exposure may occur at lower exposure levels than previously thought (Järup, 2003). Low levels consumed over long periods of time can build up in the kidneys and cause certain types of bone diseases such as osteoporosis and osteomalacia. These may be due to kidney malfunction and inability to properly metabolise vitamin D, in turn disrupting the proper absorption and excretion of calcium (BSR, 2002).

Metals like lead have equally become a grave concern due to the adverse effects they have on human beings (FCEAD, 2005). Children are particularly susceptible to lead exposure due to high gastrointestinal uptake and the permeable blood–brain barrier (Järup, 2003). Lead has been found to accumulate in the body's organs, including the kidney and brain, and impairs the proper functioning of these organs as well as the gastrointestinal tract, the central nervous system and blood cells. High levels of lead in the body system can cause convulsions, coma and in severe cases death. Apart from children, pregnant women and foetuses are also susceptible to the effects of lead. Lead exposure can impair both physical and mental development in children, and lead to progressive mental deterioration and behavioural disorders (BSR, 2002).

1.7 PROBLEM STATEMENT

Water quality degradation continues to be a problem in Malawi despite the efforts of national environmental programs. The challenge has further been compounded by lack of local capacity to carry out analyses of important parameters other than BOD which could assist in effective monitoring by relating pollutants identified in industrial effluents as pollutant sources to the water characteristics in the streams hosting the industrial area. The monitoring being done by local authority in Blantyre City and spot checks by the Water Resources Board are inadequate to curb down point source pollution due to the limited parameters being monitored as such the

likelihood of having the water bodies being polluted by toxic pollutants all the time is high thereby putting lives of many people at risk.

In advanced countries, environmental monitoring agencies are more effective and environmental laws are strictly followed. General environmental quality monitoring is compulsory and the monitoring of the quality of water resources is done on a regular basis (Neal et al, 2000; Fakayode, 2005). As a result, any abnormal changes in the environmental or water quality can easily be detected and appropriate action taken before the outbreak of epidemics. The case is quite the opposite in many developing countries like Malawi where it is difficult to trace the point sources of pollution due to lack of capacity and data pertaining to the quality of effluent associated with particular industries. The problem has been worsened by the fact that industries within the jurisdiction of the city of Blantyre are permitted to dispose of effluents into the municipal sewers and water bodies provided the quality of such effluents is within the outdated regulatory standards as set out in the city Council By-Laws 1982 (City Council By- Laws, 1982). The standards set limits on few parameters like BOD (20 mg/l), COD (60 mg/l), and these limits set by the local authorities for toxic chemicals do not account for either possible synergistic effects, chemical speciation or the cumulative impacts of long-term exposure on humans, animals or environment (Tolosana and Ehrlich, 2000). It could be of quite significance if the monitoring included important parameters like nitrates, phosphates and heavy metals

Although some studies have been carried out on the quality of watercourses that pass through the industrial area of Blantyre to determine the impact of industrial pollution, not much has been done to determine the quality of effluent emanating from industries as a point source. Karim and Darrington (1995) alluded to the fact that information on quality and quantity of industrial effluent is sparse because access to sampling points in industries is often refused. The situation is similar in Blantyre City where free entrance to industries is limited to environmental regulatory bodies that by law are required to inspect industries at will. However, these bodies lack the capacity to carry out assessments of a wide range of parameters which could in full show the quality of wastewater emanating from industries as a point source. This therefore has created a problem that there has been no apparent investigation into the composition of effluents discharged from industries although regular testing for Biochemical Oxygen Demand and Chemical Oxygen Demand is undertaken by the local authority.

The identification and characterization of sources are critical to the successful development and implementation of a watershed plan and the control of pollutant loading to a stream. Characterizing and quantifying watershed pollutant sources can provide information on the relative magnitude and influence of each source and its impact on stream water quality conditions (USA EPA, 2005).

1.8 OBJECTIVES OF THE STUDY

1.8.1 General Objective

The general objective of the study was to investigate the quality of industrial effluents discharged by industries in Blantyre city, efficiency of wastewater treatment plants and impact of industrial effluents on the water quality of streams passing through the industrial areas.

1.8.2 Specific Objectives

1. To determine the quality of effluent being discharged by industries and their effect on selected streams and wastewater treatment plants in terms of nitrate, phosphates, sulphates, metals (cadmium, chromium, copper, iron, lead, manganese, nickel, calcium, potassium and zinc), pH, temperature, suspended solids, alkalinity, electrical conductivity, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, chlorides, oil and grease.
2. To ascertain the sources of pollutants from the industrial activities and the anti pollution measures used by industries prior to discharging of effluent.
3. To evaluate the efficiency of Blantyre City Assembly treatment plants and industrial pretreatment plants in reducing the pollution load in terms of nitrate, phosphates, sulphates, metals (cadmium, chromium, copper, iron, lead, manganese, nickel, calcium, potassium and zinc), pH, temperature, suspended solids, alkalinity, electrical conductivity, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, chlorides, oil and grease.

CHAPTER 2: MATERIALS AND METHODS

2.1 SITE DESCRIPTION

2.1.1 General

The study area is the area contained within Blantyre city boundary. Blantyre city is the largest urban settlement in the Republic of Malawi with approximated population of 700, 000 people and it covers an area of some 228 square kilometres. It is located in the Shire Highlands in the southern part of Malawi (Figure 2.1)

Climatically, Blantyre like most of the districts in Malawi has two main seasons during the year, the dry and the wet. The wet season lasts from November to May and the remainder of the year is dry, with temperature increasing until the onset of the next rains.

The Blantyre city area lies within the Shire highlands with topography ranging from 800m to 1600m above sea level with several hills in its boundaries. The core of the highlands is a broad northeasterly trending ridge hills extending from Thyolo, in the south to Zomba in the north. To its northwest it is bounded by the edge of the rift valley, but its south eastern limits are transitional into Phalombe plain. The hills are the headwaters of several streams, which radiate outwards from the city. These streams flow into nine distinct catchment areas.

The Mudi river and its tributary, the Naperi streams form the main drainage from Blantyre area. These watercourses gradually deepen their valleys until they descend the dissected edge of the Shire highlands surface, through narrow gorges, to where the Mudi is joined by the Naperi and continues to Shire River.

The geology and soils in Blantyre city are formed, mainly by a series of charnockitic rocks that are either intermediate or basic in character. The intermediate species is more predominant. The rocks generally are of granulite facies and diaphoresis to the eastward of Shire Highland ridge (BCA, 1995).

Originally the Shire Highlands was mostly covered with closed evergreen forest, fringing the many perennial streams and capping hills and mountains above 1370 m. Due to considerable

clearing and cultivation during the recent years, only scattered fragments of the original *Brachstegia* woodland remain, mostly on private estates and the lower slopes of rocky hills. Most of the landscape today is characterised by plantations of exotic trees and particularly the ubiquitous Blue Gum (*Eucalyptus saligna* and *E. grandis*). Riverine forest sparsely occurs but where heavy felling has taken place or where cultivation has been taken right up to the bank, the forest has degenerated completely and all that is left consists of isolated tall trees standing on an eroding gulley.

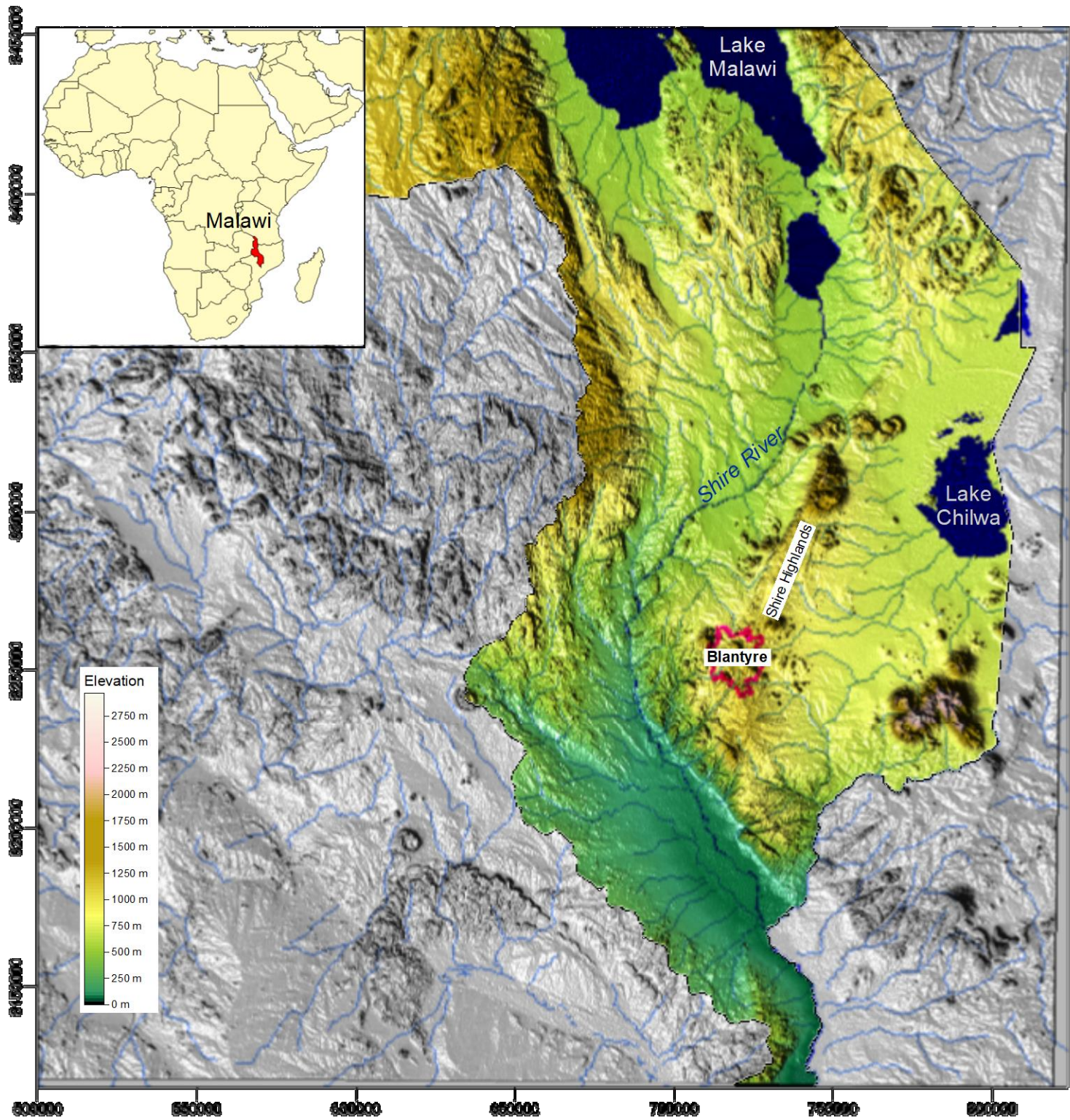


Figure 2.1: Location of Blantyre city in Malawi

2.1.2 Industrial sites and rivers in Blantyre city

Blantyre has eight designated industrial areas namely Makata, Ginnery corner, Maselema, Limbe, Chirimba, South Lunzu, Maone and Chitawira (Figure 2.2). Of these, Makata, Ginnery corner, Maselema, Limbe, Chirimba and Maone are actively hosting industries whilst South Lunzu is yet to be developed. The existing industrial sites are further categorized into heavy and light industrial sites. Makata and Limbe, for example are the sole heavy industrial sites hosting more than thirty companies whilst Chirimba industrial area though designated a heavy industrial area, is the least developed in terms of number of industries in the area. Apart from Makata, Ginnery corner industrial site is another active site followed by Limbe and Maselema and the least is Chirimba and Maone industrial sites. Chitawira and Maselema are classic examples of light industrial areas (BCA, 2006). All the industrial areas are allocated along the banks of the main rivers or streams of Blantyre city. Makata industrial area lies between Mudi and Nasolo streams whilst Ginnery corner industrial area is along Mudi River. Maselema industrial area exists along the Naperi river and Chirimba stream hosts Chirimba industrial area.

Industries within Blantyre city are grouped into either wet or dry industry depending on the volume of the water used in the industries. Industries that use water as part of the production process and cleaning production line are described as wet industries because they generate a lot of effluent whilst dry industries are those that use water for ordinary sanitary usage within the premises. Portland Cement Company is a typical example of dry industry whilst Southern Bottlers is listed as wet industry (BCA, 2006)

2.1.3 Wastewater treatment Plants

The research included investigating the efficiency of treatment plants within the city in reducing the pollution levels in effluents. The responsibility of treating wastewater within the city rests in the hands of Blantyre city Assembly. According to the Blantyre City Assembly industrial profile report (2006), the city has three functional treatments plants namely Limbe (Figure 2.3), Soche and Blantyre wastewater treatment plant. About 70% of wastewater loading into Blantyre wastewater treatment plant is industrial effluent coming from mainly Makata and Ginnery corner industrial areas. The wastewater plant combines conventional trickling filters and pond system in treating the effluents. Soche sewage plant, which is

conventional trickling filter, receives about 30% of its effluent from the light industrial area of Maselema and Ginnery corner. The rest 70% is domestic effluent emanating from residential areas, sanitary sewage from industries and storm water. Limbe wastewater treatment plant, which uses pond system receives almost equal volumes of industrial and domestic effluent. A network of sewerlines provided by city assembly conduits the effluents from all designated areas to these treatments plants. There exist some pre-treatment plants installed by individual companies in an attempt to reduce the pollution load before discharging effluent into either sewerlines or water streams. Figures 2.4 to 2.6 show some of the pre-treatment plants used by industries.



Figure 2.3: Limbe wastewater treatment plant showing pond system



Figure 2.4: Pretreatment plant at a textile industry- Mapeto David Whitehead Ltd



Figure 2.5: Oxidation ditch at dairy industry- Dairiboard



Figure 2.6: Oil interceptor at confectionery industry- Universal industries Ltd

2.2 SAMPLING AND SAMPLE PREPARATION

Sampling was done in the months of October to November, 2005 for dry season and February, 2006 for wet season. Grab sampling was used in collecting water and wastewater samples from all sampling points. Samples were collected in triplicates of 1 litre bottles. Samples (1 litre bottle) meant for heavy metal analysis were acidified on the spot with concentrated nitric acid (2 ml) (APHA, 2005).

Effluent samples were collected from the selected industries representing the categories of industries in Blantyre City. Water samples from the streams were collected from the selected points along the Mudi, Nasolo, Naperi, Chirimba and Limbe streams. The points consisted of points before industrial area, middle and point after industrial activities. Wastewater samples from the major treatment plants were collected before and after treatment process. In addition samples were collected from the streams into which the treatment plants discharge final effluents above and below point of discharge. Figure 2.7 shows all the sampling points.

Sampling Points for Water and Waste Water in Blantyre City

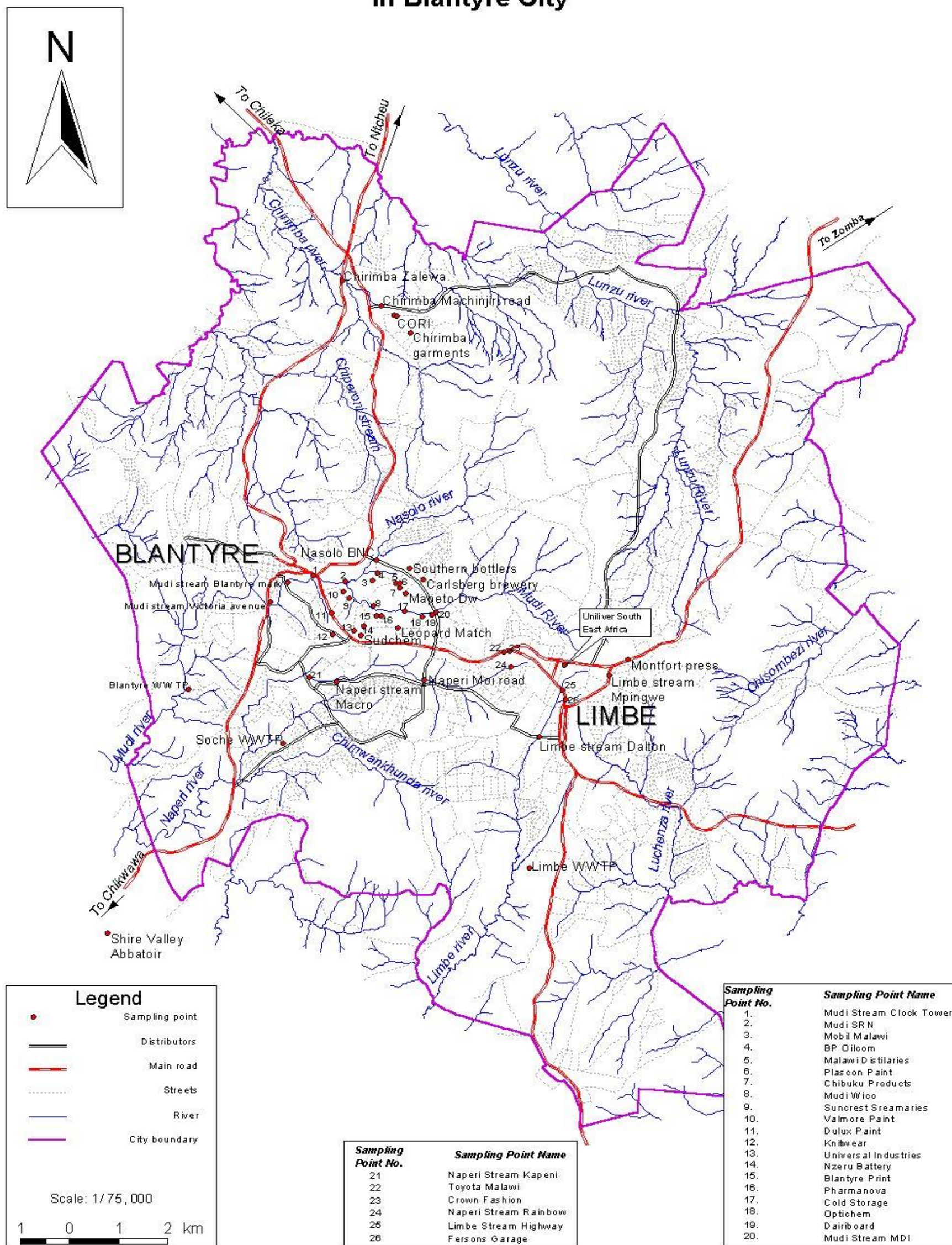


Figure 2.7: Map of Blantyre city showing sampling points.

2.3 CHEMICAL ANALYSES OF WATER AND WASTEWATER

2.3.1 Determination of nitrates

Sodium salicylate solution (10 ml, 0.5% w/v) was added to a filtered sample (20 ml) in a 250 ml Erlenmeyer flask before evaporating to dryness over a water bath (APHA, 1985). After cooling, concentrated sulphuric acid (2 ml) acid was added and the raw mixture was left to stand for 10 minutes, diluted with deionised water (25 ml), gently warmed to dissolve any remaining residues and neutralised with sodium hydroxide solution (10 ml, 25%, w/v). When a yellow colour developed, the mixture was quantitatively transferred into a 100 ml volumetric flask and then diluted to the mark with deionised water (AOAC, 1990).

Nitrate stock solution (1000 ppm) was prepared by dissolving predried potassium nitrate (0.7218g) dried in an oven at 105°C for 24 hours in deionised water and diluted to the mark in a 1-Litre volumetric flask. Working standard solutions of 0.0, 1.0, 2.0, 3.0, 5.0, 7.0, 10.0, 15.0 ppm were prepared by subjecting equivalent volumes to the digestion procedure given to sample aliquots as outlined above. Finally, absorbance of the working standard solutions and samples were determined calorimetrically at 410 nm using a Jenway model No. 6405 digital spectrophotometer (APHA, 1985).

2.3.2 Determination of phosphates

Perchloric acid digestion was used to determine orthophosphates. Sample (50ml) was transferred into a 250 ml Erlenmeyer where it was acidified to methyl orange with concentrated nitric acid (5ml), and then 5 ml of concentrated nitric acid was added. The sample mixture was thereafter evaporated on a hot plate to 15 to 20ml. Later, concentrated nitric acid (5ml) and concentrated perchloric acid (10 ml) were added. After adding a few boiling chips the sample mixture was heated until dense white fumes of perchloric acid appeared. In instances where the solution was not clear, the neck of the flask would be covered by a watch glass and the solution left to boil until it cleared. If the solution was still not clear, 10ml more of nitric acid was being added to aid oxidation. Digested solution was then cooled and 1 drop of aqueous phenolphthalein solution added. The solution was neutralised with sodium hydroxide (6M) solution until it reached the end point indicated by the solution just turning pink and later it was made up to 100ml with distilled water (APHA, 1985).

A 500-ppm phosphate standard stock solution was prepared by dissolving anhydrous KH_2PO_4 (109.75mg) in deionised water and finally diluting to the mark in a 500 ml volumetric flask (APHA, 1985). Using the prepared standard stock solution, 1 Litre volume of an intermediate stock solution (100 ppm) was prepared from which standard working solutions of 0.0, 1.0, 2.0, 5.0, 7.0, 10.0, 12.0, 15.0, 20.0 ppm were prepared. Finally, absorbances of samples and working standard solutions were determined at 470 nm using a Jenway model No. 6405 digital spectrophotometer.

2.3.3 Determination of sulphates

This analysis followed a turbidimetric method as outlined in APHA(1985), in which a buffering solution (20 ml), comprising a mixture of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ (30 mg), sodium acetate (5g) and glacial acid (20 ml) , was mixed with 100 ml of sample in an Erlenmeyer flask while stirring with a magnetic stirrer (APHA, 1985). Then, a spoonful of BaCl_2 crystals was added to the mixture stirred for a minute.

Sulphate stock solution (1000 ppm) was prepared by dissolving anhydrous sodium sulphate (0.1479g) in deionised water and then diluted the resultant solution in a 1-Litre volumetric flask with deionised water. Then, 0.0, 0.5, 1.0, 1.5, 2.0, 3.0 and 4.0 ml of the standard stock solution were diluted with deionised water in 100 ml volumetric flasks to get working standard solutions of 0.0, 5.0, 10.0, 15.0, 20.0, 30.0 and 40.0 mg/L, respectively. Absorbances of working standard solutions and samples were determined at 420 nm using a Jenway model No. 6405 digital spectrophotometer.

2.3.4 Determination of metals

Water and wastewater samples for the determination of metals followed nitric acid digestion. A well-homogenized unfiltered sample (100ml) was transferred to a 250ml flask and 5ml of concentrated nitric acid was added to it. The mixture was then brought to a slow boiling and evaporated on a hot plate until the volume was reduced to 15-20ml. Concentrated nitric acid (5 ml) was added to the solution and the flask covered with a watch glass before heating it to obtain a gentle refluxing. The heating continued whilst adding 5ml portion of nitric acid until the solution became light coloured clear solution. Finally concentrated nitric acid (2 ml) was added

to dissolve any remaining residues and later the solution was quantitatively filtered into 100ml volumetric flask and diluted to the mark (APHA, 1985).

Brief procedures that were used during the preparation of standard stock solutions for various metals analysed in water samples are outlined below. For each of the metals, 20 mL of 1000ppm standard stock solution were diluted with deionised water in a 100 mL volumetric flask to prepare an intermediate stock solution (200 ppm). Then, appropriate volumes of the intermediate stock solutions (0.0, 0.25, 0.5, 1.0, 2.5, 5.0 and 7.5 mls) were diluted with deionised water in 100 mL volumetric flasks to prepare working standard solutions of 0.0, 0.5, 1.0, 2.0, 5.0, 10.0 and 15.0 ppm, respectively. Absorbances of working standard solutions and water samples were determined using Shimadzu model AA-680 and Buck Scientific model no. 200A Atomic Absorption Spectrophotometers.

2.3.4.1 Cadmium metal

A standard stock solution (1000 ppm) was prepared by dissolving cadmium metal (1.00g) in concentrated. nitric acid (4ml) before diluting the resultant solution with deionised water in a 1-Litre volumetric flask. Absorbances of the working standard solutions and samples were read at 228.8 nm.

2.3.4.2 Manganese metal

A standard stock solution (1000 ppm) was prepared by dissolving manganous sulphate monohydrate (3.08 g) in deionised water (150 ml) before adding concentrated nitric acid (2ml) to the solution and diluting with deionised water in a 1-Litre volumetric flask. Absorbances of the working standard solutions and samples were read at 279.5 nm.

2.3.4.3 Copper metal

A standard stock solution (1000 ppm) was prepared by dissolving copper (1.00g) metal in concentrated nitric acid (15 ml) before diluting the solution with deionised water in a 1-Litre volumetric flask. Absorbances of the working standard solutions and samples were read at 324.8 nm.

2.3.4.4 Chromium metal

A standard stock solution (1000 ppm) was prepared by dissolving anhydrous potassium dichromate (2.83 g) in deionised water (200ml). Concentrated nitric acid (2 ml) was added to

the solution before diluting with deionised water in a 1-Litre volumetric flask. Absorbances of the working standard solutions and samples were read at 357.9 nm.

2.3.4.5 Zinc metal

Zinc metal standard stock solution (1000 ppm) was prepared by dissolving zinc metal (1.00g) in nitric acid (20mL, 50% v/v in deionised water) and the solution was diluted with deionised water in a 1-Litre volumetric flask. Absorbances of the working standard solutions and samples were read at 213.9 nm.

2.3.4.6 Lead

A standard stock solution (1000 ppm) was prepared by dissolving lead nitrate (1.60g) in deionised water (200 ml). Concentrated nitric acid (2 ml) was added to the solution before diluting with deionised water in a 1-Litre volumetric flask. Absorbances of the working standard solutions and samples were read at 283.3 nm.

2.3.4.7 Nickel

A standard solution (1000ppm) was prepared by dissolving nickel nitrate hexahydrate (4.95g) in water (150ml). Concentrated nitric acid was added to the solution and the solution was diluted to 1L in a volumetric flask. Absorbance of the working standard solutions and samples were read at 232.0 nm.

2.3.4.8 Iron

A standard stock solution (1000ppm) was prepared by dissolving iron wire (1.00g) in 1+1 nitric acid water (50ml). The standard solutions used in the final determination were 0.00, 0.5, 1.0, 2.0, 5.0 and 10.0ppm. Absorbance of the working standard solutions and samples were read at 248.3 nm

2.3.4.9 Potassium

A standard stock solution (1000ppm) was prepared by dissolving potassium chloride (1.907g) dried at 110 °C and later diluted to 1-Litre with deionised water. The standard solutions used in the final determination were 0.00, 0.5, 1.0, 2.0, 5.0 and 10.0ppm. Absorbance of the working standard solutions and samples were read at 769.9 nm.

2.3.4.10 Calcium

The standard stock solution (1000ppm) was prepared by adding deionised water (50 ml) to CaCO_3 (2.497 g) and adding dropwise concentrated hydrochloric acid (10 ml) to complete dissolution. The solution was subsequently diluted to 1000 ml mark in volumetric flask. The stock solution was used to prepare a 100ppm intermediate stock solution from which the working standard solutions were prepared. The standard solutions used in the final determination were 0.00, 0.5, 1.0, 2.0, 5.0 and 10.0ppm. Absorbance of the working standard solutions and samples were read at 422.7 nm.

2.3.5 Determination of pH

The pH of water samples was done at sampling points using a glass electrode Kent EIL 7020 pH meter. Before determining the pH, the meter was calibrated using pH 7 and pH 4 buffering solutions, respectively. The electrode of the meter was rinsed with deionised water before determining the pH of any subsequent sample to prevent inter-sample contamination (APHA, 1985)

2.3.6 Determination of Dissolved Oxygen and Temperature

Dissolved Oxygen (DO) and temperature levels in water samples were done during sampling using HI 9145 Microprocessor Auto calibrating DO meter which measured both DO and temperature. The meter was rinsed with deionised water before determining the DO and temperature of any subsequent sample to prevent inter-sample contamination.

2.3.7 Determination of electrical conductivity

The electrical conductivity (EC) of water samples was determined in the field using WPA – CM 35 conductivity meter. The electrode of the meter was rinsed before dipping into subsequent water samples to prevent inter-sample contamination (APHA, 1985).

2.3.8 Determination of alkalinity

Determination of the alkalinity of water samples involved an acid-base titrimetric method (Skoog *et al*, 1994). Water and wastewater sample (25 mL) was pipetted into a 250 mL Erlenmeyer flask into which 2 - 3 drops of phenolphthalein were added to determine phenolphthalein alkalinity. Then later 2 - 3 drops of methyl orange indicator was immediately added to the sample solution to determine total alkalinity. The mixture was then titrated with sulphuric acid (0.02N) until the methyl orange end point. The total volume of the acid was recorded for the two types of alkalinity.

2.3.9 Determination of Biochemical Oxygen Demand (BOD)

2.3.9.1 Preparation of dilution water

Dilution water was prepared by adding 5 mL each of $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ (0.125g in 1 Litre of deionised water), anhydrous CaCl_2 (6.875g in 250 mL of deionised water), $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ (6.25g in 250mL of deionised water) and phosphate buffer of pH 7.2 to 5 litres of deionised water(AOAC, 1990).

2.3.9.2 BOD determination

An aliquot of sample (20ml) was placed in a sample flask to which distilled water was added and 2.0ml 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 be pipetted into two BOD bottles, one for incubation for 5 days at 20°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 $\text{MnSO}_4 \cdot \text{H}_2\text{O}$ solution (182g in 500 mL of deionised water) was added. Then, 2 mL of alkali-azide-sodium iodide solution (5g NaN_3 , 250g NaOH and 70g 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 conc. sulphuric acid was added to the mixture in the reagent bottle.

The stopper was then replaced and the reagent bottle shaken until all the precipitate 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.

2.3.10 Determination of Chemical Oxygen Demand

To about 20 ml of the homogenized sample in the reflux condenser, was added a 10ml aliquot of standard potassium dichromate (0.02M) containing mercuric sulphate and 30mls of sulphuric acid containing silver sulphate. The mixture heated for 2 hours in the range of 148 and 150°C and then cooled to room temperature. The condenser was washed by distilled water and the final mixture was used to make 100ml solution which was titrated against 0.12M ammonium iron (II) sulphate(FAS) using ferroin indicator.

To calculate COD levels, the following equation was used:

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

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.

2.3.11 Determination of Chlorides

Chlorides were determined by using an argentimetric method which 100ml or a suitable portion was diluted to 100ml and the samples were neutralized (pH 7 -10) by either sulphuric acid or sodium hydroxide (APHA, 1985). If the sample was highly coloured, aluminium hydroxide (3 ml) was added and the mixture left to settle and it was later filtered. Later 1ml of 30% H₂O₂ was added to inhibit sulfite interference and the mixture was stirred for 1 minute. About three drops of potassium chromate (prepared by dissolving potassium chromate (10.0g) in 1000ml distilled water) indicator was added and the sample mixture was directly titrated with N/50 silver nitrate (prepared by dissolving of silver nitrate (3.397g) in 1000ml of distilled water) until the end point of brick red colour was reached. The concentration of the chloride was calculated on the ratio that 1 ml of N/50 silver nitrate solution is equal to 7.1mg/L Cl.

Aluminium hydroxide suspension was prepared by dissolving 125g aluminium potassium sulphate or aluminium ammonium sulphate, $\text{AlK}(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ or $\text{AlNH}_4(\text{SO}_4)_2 \cdot 12\text{H}_2\text{O}$ in 1 litre distilled water. The solution was warmed to 60°C and 55ml concentrated ammonium hydroxide shall be added slowly with stirring. The solution was left to stand for 1 hour then later transferred to a large bottle and the precipitate washed by successive additions with thorough mixing and decanting with distilled water. The suspension occupied approximately a volume of 1 litre.

2.3.12 Determination of suspended solids

Exactly 10ml of a sample was filtered through a pre weighed glass fibre filter placed on a vacuum pump. Three successive 10ml volumes of distilled water were used to wash the sample on the filter so as to allow complete drainage between washings and suctioning continued until the filtration was complete (APHA,1985). Afterwards the filter was removed from the vacuum pump to an aluminium or stainless planchet as a support. Then later the filter was 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 suspended solids (SS) was as follows:

$$\text{mg/l SS} = \frac{(A - B) \times 1000}{\text{Sample(ml)}}$$

Where: A = weight of filter +dried residue, mg

B = weight of the filter, mg

2.3.13 Determination of Oils and Grease/fat

Exactly 100mls or a smaller volume made up to 100mls with distilled water of homogenized sample was measured into a 250 ml Erlenmeyer flask. Few drops of methyl orange indicator were added. Then the sample was acidified with 3mls of concentrated sulphuric acid, which exhibited purple colour in the presence of the indicator. Thereafter the entire sample was transferred into a 1000 ml separating funnel with aid of 50ml of petroleum spirit carefully rinsing the sampling flask. The stoppered funnel was shaken vigorously for 1 minute as to allow the water phase to separate until a sharp interface was obtained. The water phase was drawn off

into a sampling flask whilst the petroleum spirit layer was transferred into a weighed 250ml quick fit flask. The procedure was repeated three times using 50mls petroleum spirit. The extracts were filtered through a folding filter paper. The solvent was extracted with the aid of Soxhlet extracting unit. The flask containing fatty matter was dried at 105 °C for one hour, and then later it was cooled in desiccators and weighed on analytical balance.

Calculations:

$$\text{mg/l TFM} = \frac{(A - B) \times 1000}{\text{Sample}(ml)}$$

Where A= Weight of the flask with Oil

B= Weight of flask

2.4 OBSERVATIONS

The researcher visited the industries to acquaint with the production processes, but also observe the prevailing wastewater treatment and disposal methods being practiced by each industry under study as to appreciate anti pollution measures.

2.5 KEY INFORMANTT INTERVIEWS

Direct interview were administered to the key informant (Production, Technical and Quality Assurance managers) using guiding questions so as to comprehend the production processes and sources of the effluent being generated (Appendix 2). One key informant was interviewed from each industry under study including some from Blantyre City Assembly.

DATA ANALYSIS

- i. The means for each analyte were calculated. The means for stream water samples were compared with maximum limits set by Malawi Bureau of Standards and World Health Organisation guidelines on surface water. The average data for levels of pollutants in the industrial effluent were compared to the local authority public sewer discharge limits as used in Blantyre and India, Nepal, Singapore, and Cape Town cities.
- ii. The Statistical Package for Social Scientist, SPSS windows program (version 12.0) was used to analyse the data. ANOVA, Kruskal Wallis, Man- Whitney, Correlation, Regression analysis and independent t test were used to determine significant differences

in the levels of pollutants in the samples between sites. Where ties existed, Least Significant difference (LSD) from ANOVA was performed on each paired group to evaluate which groups are statistically different from one another. A significance level (α) of 0.05 was used for all statistical tests in this study.

CHAPTER 3: RESULTS AND DISCUSSION

3.1 PHYSICOCHEMICAL CHARACTERISTICS OF INDUSTRIAL EFFLUENTS

Blantyre city is endowed with rich water resources which could be sufficient in quantity to supply the local community with water for portable, domestic and industrial uses, the quality has been poor purportedly due to pollution emanating from industrial wastewater (Malawi State of Environment report, 2002). As of 2006 there were more than thirty industries classified as abattoirs, battery, brewery, bottling, chemicals manufacturer, dairies, fertilizer, matchstick, motor oils, pharmaceuticals, paint, printing, petroleum refineries, vegetable cooking oil, textile (BCA, 2005). The characteristics effluent from these industries are presented and discussed in the preceding paragraphs. Comprehensive data on the characteristics of industrial effluent are given in appendices 2, 3, 4 and 5.

3.1.1 Levels of Temperature in industrial effluents

Temperature is a crucial parameter, which requires monitoring before the effluent is discharged because of the adverse effects it can cause to both the sewer workers and the general environment (NGRDC, 2005).

The effluent temperatures of most of the industries were below the maximum limit of 40°C set by Blantyre City Assembly except for effluent from Battery companies where the temperature reached 71°C in the dry season and 100°C in the wet season (appendices 3 & 4). At both periods of study dissolved oxygen was not detected most likely due to the high temperatures. The high temperatures observed in battery industry are due to the fact that boiled water is used for hardening white paste in order to enhance its sticking to the carbon rod in the dry cell before it is wrapped with outer cardboard. In the study of industrial effluents carried out in Gaborone, Botswana by Emongor et al (2005), it showed levels of temperature of effluents being less than local authority maximum limit of 35°C similar to the scenario depicted in this study where all industries except battery industry were below the maximum limit of 40°C.

3.1.2 Levels of electrical conductivity in industrial effluents

Electrical conductivity is a measure of a material's ability to conduct an electric current. The levels of electrical conductivity in the dry season ranged from 1.0 millisiemens/ cm in the pharmaceutical industry to 19000 millisiemens/cm at edible oil refinery A. The seemingly abnormal value registered in the dry season could be due the usage of strong acids commonly used in treating effluents from industries that process cooking oil. As shown in appendices 3 and 4, the levels of anions at the edible oil industry were high as 33.23 mg/l for sulphates, 748.46 mg/l for phosphates and 37.99 mg/l for nitrates suggesting that the observed conductivity might have been due to these dissolved ions. Acid is used to lower the pH in order to allow the flocculants, which are usually polyelectrolytes to crumb the oil layers into scum, which is eventually skimmed off. The effluent is later neutralized with sodium hydroxide to maintain the effluent within the neutral range.

The levels of conductivity in the wet season ranged from 0.7 mS/cm in petroleum storage station A to 98 mS/cm in battery industry. The majority of categories of companies' levels fell within the ranges of 0.7 to 26.0 in the wet season and 1.0 to 45.0 in the dry season (appendices 3 and 4). As reported in the study by Fakayode, 2005, that high levels of the electrical conductivity in the effluents could be generally attributed to the high levels of species such as sulphates, chlorides, and phosphates and heavy metals present in the effluent, the observation could be also true for this study where most of the effluent contained significant levels of these dissolved ions. Nevertheless the concentrations of heavy metals might have not been significant contributors to the observed levels of conductivity because they were relatively lower than the rest of the constituent parameters.

3.1.3 Levels of chlorides in industrial effluents

In investigating the levels of chlorides in the industries under study as potential source of this halide, it was observed that all industries produce effluent that contains some chlorides (Figure 3.1)

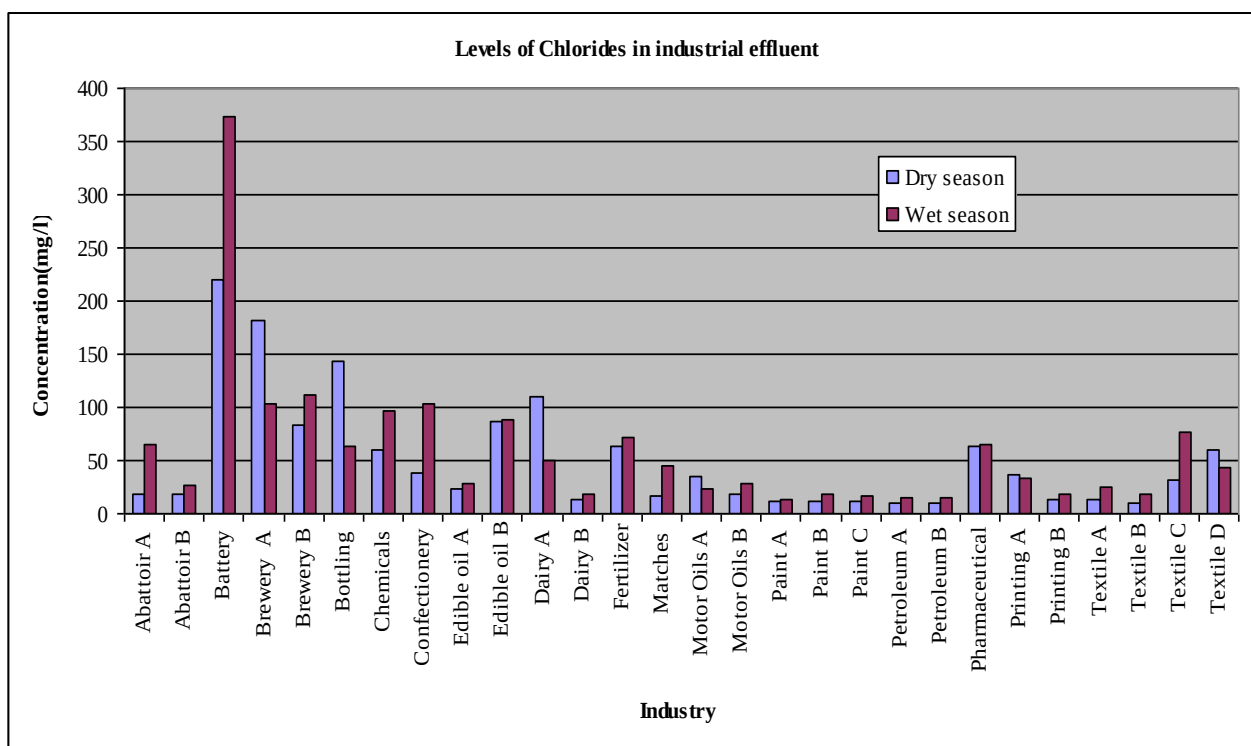


Figure 3.1: Levels of chlorides in industrial effluents.

In both the wet and dry seasons, the battery industry registered highest levels of 372.81 ± 3.46 mg/l and 220.0 ± 9.20 mg/l respectively (Appendix 3&4, figure 3.1). The chloride levels in the battery industry were significantly higher than the rest of the industries (ANOVA; $p < 0.05$). The two petroleum industries were the least in the dry season registering 9.20 ± 0.60 mg/l and 9.20 ± 0.40 mg/l whilst paint A showed the least value of 12.80 ± 0.90 mg/l in wet season.

At 95% confidence interval, independent t-test showed no significant differences of the mean chloride levels between the two seasons ($p = 0.585$). Nevertheless the levels of chlorides varied among the industries with some registering levels that did not differ from each other whilst some differed significantly.

In the dry season effluents from abattoirs (A&B), matchstick and motor oil B did not differ significantly from each other, likewise industrial effluents from chemicals, fertilizer, pharmaceutical and textile D. Effluents from confectionery, motor oil A, printing A and textile had chlorides concentrations that did not equally differ significantly whilst the least levels of chlorides that showed no difference were noted in effluents from dairy B, paint (A,B&C), petroleum (A&B), printing B and textile (A&B). Effluents from battery, bottling, brewery A,

edible oil A and dairy A had highest levels that significantly differed from each other and the rest of industries (ANOVA; $p < 0.05$).

Unlike in the dry season where only four industries differed significantly from the rest of industries, the results in the wet season show 16 industries registering chloride levels that significantly differed from each other. The only industries that had chloride concentrations that did not differ significantly include combinations of abattoir A, bottling and pharmaceutical; brewery A and confectionery; dairy B, printing B paint (B&C) and textile B. However the chloride levels of the effluent discharged into the public sewer from all industries under study were below the maximum permissible limits of 400mg/l, 600mg/l and 1500mg/l as the practice is in Nepal, India and Cape Town respectively.

Besides the fact that almost all natural waters contain chloride ions and that water used in Blantyre city is chlorinated reaching the chlorine levels of 10mg/l (Blantyre Water Board, 2006) which could contribute to the trace levels in the effluents, the levels are probably exacerbated due to common salt, hydrochloric acid and other chloride compounds which are used as raw material in most of industries. A good example is in textiles industries where salt (NaCl) and oxidizing agent hypochlorite (NaOCl) is used in bleaching the garments. At a chemical industry, hypochlorite solutions used for cleaning are manufactured at the plant. In pharmaceuticals, sodium hypochlorite (5%) is used in some medicinal products as preservative agents (Changa, 2006). The chlorides levels in the battery industry can be attributed to the ammonium chloride that constitutes the gelatinous substance that surrounds the cathode, which forms an alloy with the zinc container (AIG, 2006).

A high chloride concentration imparts brackish salty taste to water and is discouraged because of health hazards. The World Health Organization (WHO) limit for chloride is 200mg/l in surface water as such if effluents from these industries are by chance discharged into the streams of Blantyre they would negatively impact the quality of water.

3.1.4 Levels of sulphates in industrial effluents

Sulphates like chlorides are contained in all natural waters, which are greatly used in industrial processes. In this study, sulphates levels in the industrial effluents in the dry season ranged from

non detectable levels of sulphates in confectionery, dairy B, and pharmaceutical industries to 342.81 ± 21.07 mg/l in matchstick company whilst in the wet season the levels were found to lie between the non detectable levels in breweries, paint A, printing A and textile A to 2059.42 ± 39.97 mg/l in edible oil refinery A (figure3.2,).

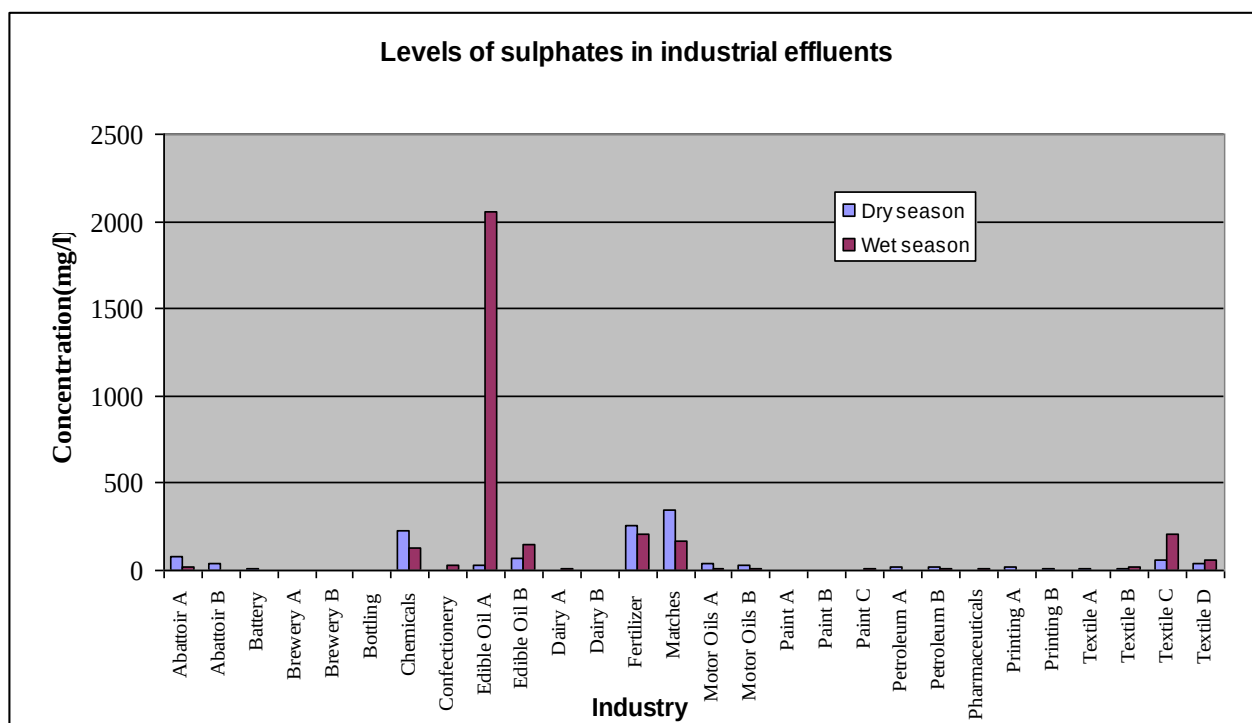


Figure 3.2: Levels of sulphates industrial effluents

Analysis of variance at 95% confidence interval showed that there were significant differences among the levels of sulphates in the industrial effluents in both the dry season ($p=0.000$) and wet season ($p=0.000$). However in the dry season, post hoc analysis showed that sulphates in effluents from battery, breweries, bottling, confectionery, dairies, paints, pharmaceutical, printing B and textile (A&B) industries which ranged from 0.0 mg/l to 7.29 mg/l had significantly lower concentrations than petroleum (A& B) and printing A. Similarly industrial effluents from edible oil A, motor oil B and textile D whose sulphates levels ranged from 28.30mg/l to 37.64 mg/l were significantly lower than a pair of abattoir B(44.32mg/l) and motor oil A (40.76mg/l). Effluent from abattoir A, chemicals, fertilizer, matchstick, edible oil B and textile C industries differed significantly from each other and had significantly higher sulphates levels than the rest of the industries.

In the wet season, nineteen of the twenty eight industries had significantly low concentrations of sulphates which ranged from 0.0mg/l in breweries (A&B), paint A, printing A and textile A to 12.54 mg/l in paint C. The levels of sulphates did not differ significantly for effluents from fertilizer and textile C ($p=0.604$) whilst the effluents from chemicals, edible oil (A & B), matchstick and textile D had levels that did not only differ significantly from any of the industry but also significantly higher than the rest of the industries.

Independent t-test showed that the mean levels of sulphates in the wet season were significantly higher than mean levels observed in the dry season ($p=0.006$). The mean level of 47.04mg/l observed in the dry season is close to the sulphates concentration of 52.0 mg/l in industrial effluents as reported by Fakoyode, 2005. However the mean levels observed in the wet season (111.74 mg/l) exceeds by double factor the mean level reported by Fakoyode. The differences could be because of the differences in raw materials used in industries which in turn determine the quality of wastewater.

The levels of sulphates in the effluent could be attributed to the sulphuric acid or sulphates salts, which are commonly used in most of these industries. Sulphate salts are used in textile industry in making fabrics whilst ferrous sulphates in particular are used in boilers. Sulphuric acid is predominantly used in treating effluents from vegetable cooking refineries.

In a study done by Mkhize et al (2000) on levels of sulphates in an edible oil refinery in South Africa, the levels of sulphates were recorded as high as 5550mg/l whilst in this study the highest levels of sulphates in a similar industry is 2059.42mg/l which does not only differ significantly ($p<0.05$) with the rest of the other categories of industries but also it is the only industry that exceed the permissible limits of 500mg/l, 1000mg/l and 1500mg/l set by Nepal, India and Cape Town respectively.

It is worthy to note that the levels of sulphates such as those at edible refinery effluents are too high that they can considerably change the characteristic of stream water into which they are discharged because sulphate in water or together with sodium or magnesium and acidity can pose special problems in the conditioning of water because of its laxative effects in concentrations greater than 30 ppm besides the fact that Sulphate water mean extreme hardness thereby curtailing the primary usage of the stream water.

3.1.5 Levels of Nitrates in industrial effluents

Excess nitrate concentrations have a potential of causing methaemoglobinaemia on the human health and eutrophication in aquatic environment. It was therefore imperative to assess the levels of nitrates in the effluents emanating from industries. The variations of nitrate levels of industrial effluent during the two seasons are provided in Figure 3.3.

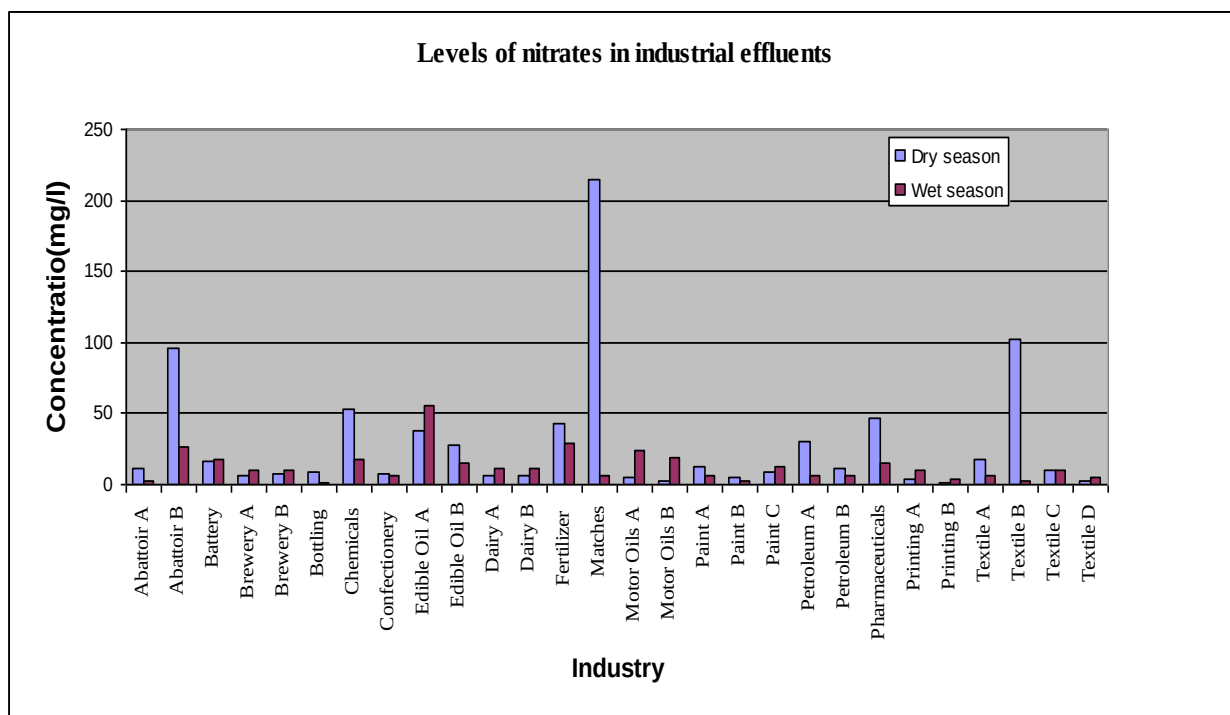


Figure 3.3: Levels of nitrates in industrial effluents

In the dry season the levels ranged from 1.76 ± 0.01 mg/l in the printing industry to 215.04 ± 39.64 mg/l in matchstick production. Analysis of variance at 95% confidence interval showed that the levels of nitrates in the dry season differed significantly among the industries with highest levels registered at matchstick industry ($p=0.000$). Post hoc analysis of the nitrates concentrations showed that effluents from twenty one of the twenty eight industries under study had significantly low concentrations compared to effluents from a pair of abattoir A and textile B as well as a combination of industrial effluents from chemicals, edible oil (A & B), fertilizer and pharmaceutical industries.

In the wet season, the nitrate levels ranged from 1.73 ± 0.0 mg/l in the bottling industry to 55.84 ± 1.27 mg/l in edible oil refinery A (Figure 3.3). The levels of nitrates in the dry season equally

differed significantly from industry to industry (ANOVA; $P=0.000$). However some industries produced effluents whose nitrate concentrations did not differ significantly and these include combinations of abattoir A, bottling, paint (B & C), printing B and textile D; battery, chemicals and motor oil B; breweries (A&B), dairies (A& B), printing A, textile D; confectionery, matches, paint A, petroleum depots (A&B) and textile (A&D); edible oil B and pharmaceutical industry. Comparison of the levels between the seasons using independent t test at 95% confidence interval showed that the mean levels of nitrates in the dry season were significantly higher than the levels in the wet season ($p=0.000$) probably due to the dilution effect caused by rain water in the wet season.

Nitrates in the industrial effluent could be attributed to the use of nitric acid in cleaning production lines (Kaonga, 2006). In industries like paints, nitrates could arise from ammonia, which is used as bacterial inhibitor in an effort to prolong the shelf life of the product (Chirwa, 2006). High levels observed in the matchstick industry effluent could be due to a fire retardant ammonium phosphate solution into which the matchstick are soaked during production process so as to prevent the stick from smouldering after glow (Kristine and Jacqueline, 2006). Ammonium phosphate is one of the dissociable ammonium salts which when placed in the water can be a source of aqueous ammonium, which under aerobic condition oxidizes into either nitrite or nitrate (USEPA, 2000). In the matchstick effluent the dissolved oxygen was recorded as high as 9.64mg/l thereby offering optimal aerobic conditions for nitrification of ammonium ion as shown in the equation: $2NH_4^+(aq) + 3O_2(g) \rightarrow 2NO_3^-(aq) + 8H^+(aq)$

In Malawi, no standards exist for discharging into the public sewer but Nepal sets the permissible limit at 50mg/l. Thus, industries that gave exceeding values above the Nepal limit include abattoir B ($95.56 \pm 28.0\text{mg/l}$), textile B ($101.73 \pm 6.43\text{mg/l}$), chemicals (52.6 ± 1.53) and matchstick ($215.04 \pm 39.64\text{mg/l}$) in the dry season whilst edible oil industry A ($55.84 \pm 1.27\text{mg/l}$) was the only non compliant in the wet season.

The trend of nitrates levels in the industrial effluent is not the same in both seasons. This may be due to variation in industrial effluent quality as a result of different production activities that can even significantly differ hourly or daily. Rainwater dilution might have also influenced the lower concentrations of nitrates in the effluent in the wet season.

3.1.6 Phosphates in industrial effluents

The levels of phosphates in the industrial effluent are provided in figure 3.4. The results indicated that the levels of phosphates in the dry season ranged from non detectable levels in textile A to 748.46 ± 1.09 mg/l in edible oil refinery A (Figure 3.4).

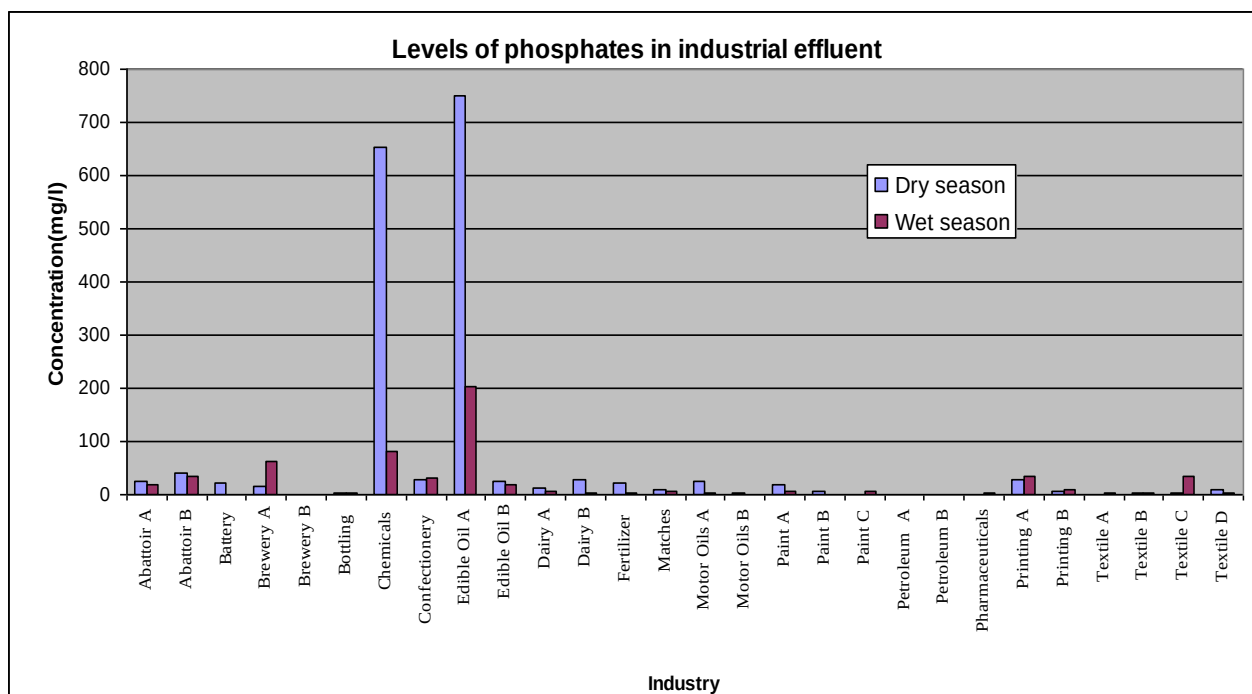


Figure 3.4: Levels of phosphates in industrial effluents

The mean levels of phosphates in effluent from edible oil refinery ‘A’ in both seasons were significantly higher than the phosphate levels in chemical manufacturers and the rest of the industries (ANOVA, 95% CI; $p < 0.05$). The concentrations of phosphates in effluent from abattoir A, battery, confectionery, dairy B, fertilizer, motor oil A, paint A, printing A and textile C did not differ significantly from each other ($p = 0.000$). The same was true for effluents from bottling, motor oil B, paints (B & C), petroleum storage, pharmaceutical, printing B, textiles (A, B and C) that levels did not differ significantly from each other and had the least phosphates levels than the rest of the industries. Other industries that did not differ significantly from each other include dairy A and matchstick industries. Effluents from abattoir A, chemicals and edible oil refinery A registered high phosphates levels that differed significantly from each other and the rest of industries. The observation on insignificant levels among the industries could suggest common usage of the raw material that contains phosphate ions.

Discharge limits set by Blantyre City Assembly and the other local authorities do not set any limit on phosphate. However comparing the levels observed in the dry season with Cape Town public sewer limit of 25 mg/l, the industries that exceeded limit were chemicals manufacturers ($653.84 \pm 32.54\text{mg/l}$), abattoir B ($39.09 \pm 1.60\text{mg/l}$), printing ($29.23 \pm 6.57\text{mg/l}$) and confectionery ($26.9 \pm 6.15\text{mg/l}$). These concentrations are very high and can contribute significantly to eutrophication if poorly managed and discharged into the natural water bodies.

During the wet season, the levels varied from 0.0 mg/l in the both petroleum depots, battery, brewery B and motor oil B industries to $203.14 \pm 9.29\text{ mg/l}$ in edible oil refinery A. Although the concentrations of phosphates in effluent differed among the twenty eight industries (ANOVA, CI 95%; $p=0.000$), some industries depicted levels that did not differ significantly from each other. Post hoc analysis of the variance showed that phosphate levels in effluents from abattoir B, bottling, dairy (A & B), fertilizer, motor oil A, paint (A&C) and textile (B&C) did not differ significantly from each other. Equally true were the non detectable levels observed in the wet season which did not differ significantly with the results observed in effluents from pharmaceutical and textile 'A' industries and together they formed the block of industries that registered the least phosphates concentrations. Other industries that did not differ significantly include pairs of confectionery and textile C ($p=0.431$), abattoir 'A' and edible oil 'B' ($p=0.065$) and a combination of dairy 'A', matchstick and printing 'B' industries. The analysis further shows that high levels of phosphates observed in effluents from brewery A, chemical and edible oil refinery A industries differed significantly from each other as well as from the rest of industries.

Independent t test on the mean levels of phosphates in the industrial effluents between the seasons showed that the levels in the dry season are significantly higher than the wet season levels ($p=0.000$).

Comparison of the quality of the effluents from industries in Blantyre to the public sewer permissible limit of Cape Town showed that industrial effluents from chemical ($82.57 \pm 6.06\text{mg/l}$), brewery A ($61.70 \pm 3.23\text{ mg/l}$), printing ($35.43 \pm 2.42\text{ mg/l}$), abattoir B ($35.14 \pm 2.83\text{mg/l}$), textile C ($34.00 \pm 6.87\text{mg/l}$) and confectionery ($30.37 \pm 4.44\text{ mg/l}$) exceed the South African regulatory limit. The non compliance of the industries could be due to absence of wastewater pretreatment plants in some of the industries whilst in other instances the poor and

outdated technology of the pretreatment plants that can not cope up with the increasing effluent load consequently reducing the retention time of the wastewater within the treatment system.

The average phosphate concentrations of 62.02 mg/l and 19.39 observed in the both seasons of study are lower than mean level of 88.10mg/l reported by Fakoyode (2005) for the industrial effluents of Nigeria effluents. This difference is probably due to variation in mode of operations and scale of productions in industries in the areas.

The observed high phosphates in the chemical manufacturers are due to the phosphate detergents that are manufactured at the plant. The prevalence of phosphates in most of the industries is probably due to the usage of phosphates detergents. In detergents, tripolyphosphates are used to stabilize dirt particles and complex Ca^{2+} and Mg^{2+} to prevent combining with the detergent molecule resulting in superior cleaning ability. However, when the soluble detergents are rinsed away, the resulting wash water has high concentrations of phosphates (MSU, 2005). In other industries like bottling company 1% diluted phosphoric acid is used for cleaning production line once in a while (Kuyeli, 2006). In the industries where edible cooking oil is either refined or used in huge amounts like confectioneries the presence of phosphate in the effluents could be attributed to the fact that crude oils, particularly soybean oil, contain significant quantities of organic phosphorus in the form of phosphatides. These compounds are removed to a large extent from the oil phase in the refining process. If refinery wash waters and soap stock are acidified, P is then translocated to the water phase (Boyer, 1996; Mkhize et al ,2000).

3.1.7 BOD and COD in industrial effluents.

The traditional methods of obtaining information on the aggregate organic pollution of water are chemical oxygen demand (COD) and biological oxygen demand (BOD). COD is the measure of biological oxygen demand plus the oxygen demand of decomposable organic and inorganic compounds (Vlessidis et al, 2005). Figure 3.5 show the levels of COD in the industries under study in both the dry and wet season.

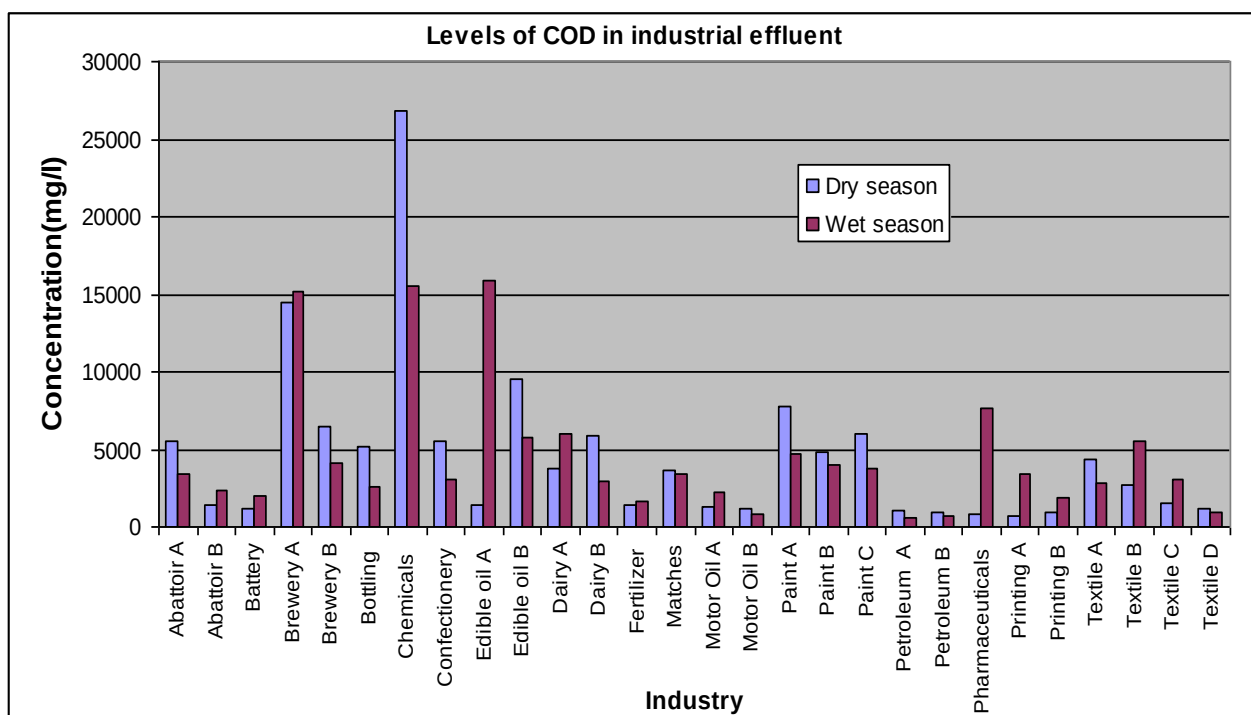


Figure 3.5: Levels of Chemical Oxygen Demand in Industrial effluents

From figure 3.5, it is clear that the industries discharge effluent with high levels of COD. In the dry season the COD levels ranged from 720.49 ± 0.89 mg/l in printing A to $26,784.33 \pm 300.09$ mg/l in chemical manufacturers whilst in the wet season the levels ranged from 605.05 ± 3.55 mg/l in petroleum storage A to 15532.00 ± 112.04 mg/l in edible oil A. The mean levels of the Chemical Oxygen Demand between the seasons did not differ significantly ($p=0.094$, $\alpha=0.05$, Independent t-test). However the levels differed significantly among the industries in both the dry and wet seasons with p values of 0.000 (ANOVA, $\alpha=0.05$).

Post hoc analysis showed that all effluents in the wet season had significantly different levels of COD from each other, a trend which was different from what was observed in the dry season where effluents from abattoir A, bottling and confectionery did not differ significantly from each other. The same observation was true for COD levels in effluents from a pair of paint C and brewery B, and a combination of abattoir B, edible oil A, fertilizer and motor oil A.

The Blantyre local authority sets 1000mg/l as effluent discharge limit for public sewers on COD for industries. The only industries that did not exceed the limit in the wet season were textile D (907.02 ± 7.70 mg/l), petroleum storages A and B (605.05 ± 3.55 mg/l and 734.06 ± 7.88 mg/l respectively), motor oil B (778.56 ± 12.04 mg/l) whilst in the dry season the industries that

complied with the permissible limit include printing A and B ($720.49 \pm 0.89\text{mg/l}$ and $998.09 \pm 12.0\text{mg/l}$ respectively), pharmaceutical ($800.09 \pm 3.20 \text{ mg/l}$) and petroleum B ($994.77 \pm 8.80 \text{ mg/l}$). Using the Cape Town trade effluent discharge limit of 5000mg/l , it was still observed that a good number of industries under study exceed the limit. In the dry season the industries include effluents from paints, dairy B, edible oil refinery B, confectionery, chemicals, bottling, abattoir A and breweries whilst in the wet season the non compliant include brewery A, chemicals, edible cooking oil refineries, dairy A pharmaceutical and textile B.

The exacerbated levels of Chemical Oxygen Demand could be due to oxidation of organic matter and numerous residual chemicals used in industries either in production or laboratories, which eventually ends up as wastewater. These could be materials like detergents, surfactants, oils, dyes, paint wastes, acids which when oxidized together with organic material in the effluents contributed to high levels of COD.

Biochemical Oxygen Demand is a measure of the amount of oxygen that bacteria will consume while decomposing organic matter under aerobic conditions (NGRDC, 2005). As expected, observed levels of BOD were relatively lower than COD levels in this study. The values of BOD in the dry season ranged from $60.0 \pm 2.2 \text{ mg/l}$ in petroleum storage B to $1570.32 \pm 22.0 \text{ mg/l}$ in dairy industry B whilst in the wet season the values ranged from $21.0 \pm 1.41 \text{ mg/l}$ in textile D to $969.35 \pm 69.93 \text{ mg/l}$ in edible oil refinery 'A'. (Figure 3.6)

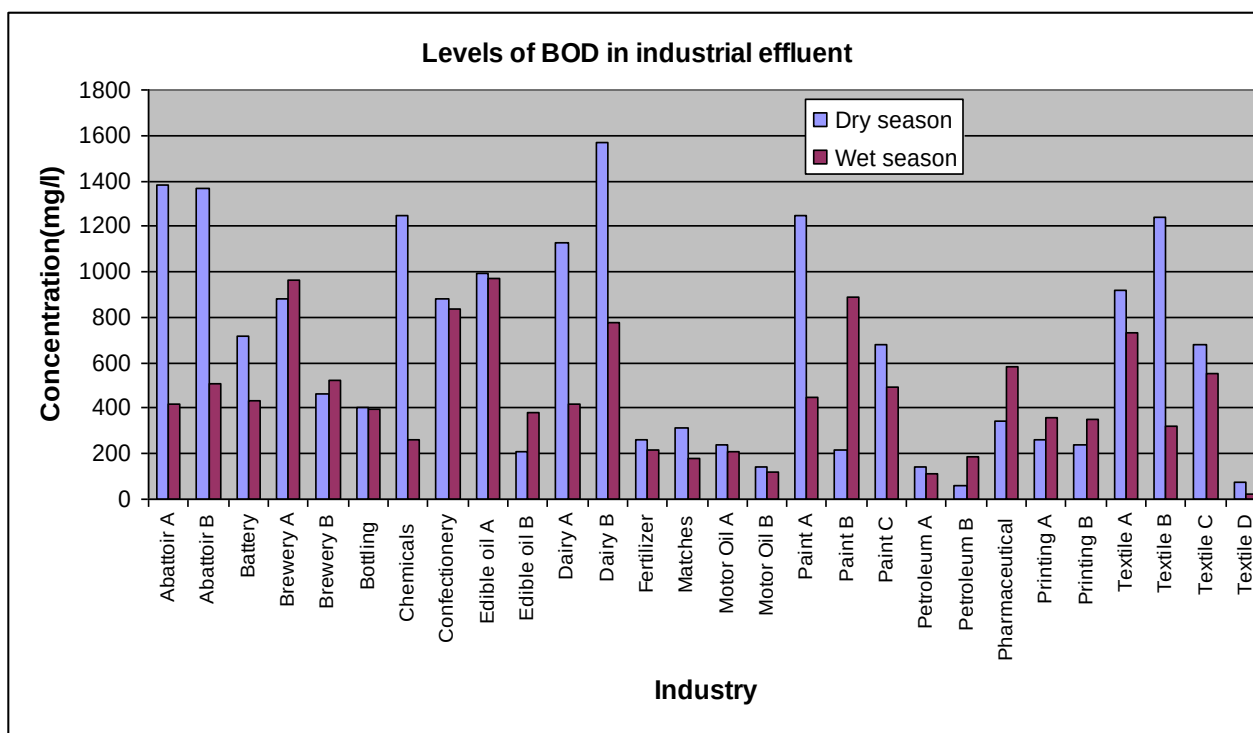


Figure 3.6: Levels of Biochemical Oxygen Demand in industrial effluents

The mean levels of Biochemical Oxygen Demand for the dry season were significantly higher than the mean levels of wet season probably due to dilution effect caused by rain water ($p=0.000$, Independent t test, CI 95%).

In each season the BOD levels among the industries differed significantly from each other with p values of 0.000 ($p < 0.05$, ANOVA). Nevertheless, some industrial effluents did not differ significantly in the levels of BOD. For example, in the dry season, effluents from brewery A and confectionery ($p=0.896$) did not differ significantly. Similarly, effluents from pairs of motor oil B and petroleum storage A ($p=0.988$), chemicals and paint A ($p=0.995$), paint C and textile C ($p=0.908$), motor oil A and printing B ($p=0.952$).

Whereas in the dry season the non significant levels were observed for pairs of industries, in the wet season, group of companies produced effluents with insignificant levels of BOD. The industries include sets of abattoir A, battery, bottling, dairy A, paint A and edible oil A; abattoir B, brewery B, paint C and textile C; brewery A and edible oil A; fertilizer, matchstick, motor oil A and petroleum B, motor oil B and petroleum A. The insignificant levels observed could suggest the use of common raw materials in the industrial productions which contains biodegradable organic matter as indicated by biochemical oxygen demand. Most notably food

processing industries produced relatively high BOD in both phases of study. This could be due to high organic content of the raw materials they use, which is easily biodegradable.

From the graphs of BOD and COD, it can be deduced that about 50% of the industries within Blantyre city discharge effluents with COD and BOD levels exceeding the Blantyre city limit on public sewer discharge which is 400mg/l for BOD 1000mg/l for COD.

Pearson correlation shows highly correlated COD and BOD levels at $\alpha = 0.01$ in the wet season ($p=0.000$) whilst in the dry season the parameters showed some correlations at α of 0.05 ($p=0.028$) implying the common source of organic pollutants which is indicated by levels of both COD and BOD. The results based on COD and BOD suggests that the majority of industries in Blantyre city are discharging organic pollutants into the council sewers and are releasing chemical toxicants resulting in a high level of oxygen demanding wastes in the effluent.

Although the findings in this study did not fully take the exact values observed by Emongor et al, 2005 on COD and BOD levels in industrial effluents of Gaborone, they are close enough to suggest that aggregate organic pollution is probably a common problem in the two cities.

3.1.8 Dissolved Oxygen in industrial effluents

Dissolved Oxygen (DO) is a very important indicator of a water body's ability to support aquatic life. In quite a good number of the industrial effluents under study, DO was not detected. The mean concentrations of dissolved oxygen did not differ between the seasons ($p=0.086$, Independent t test).

In the dry season, industrial effluents that were void of dissolved Oxygen were abattoir 'A', battery, chemical, confectionery, edible oil 'A', motor oil 'A' and textile industries whilst in wet season the list included abattoir 'B', battery, edible oil 'A', dairy 'A', fertilizer, paint 'A' and 'C', petroleum 'A' and textile 'B' and 'D' (appendices 3 and 4). This was not surprising considering the high levels of nutrients, organic loads and solids that are usually contained in the effluent. In industrial effluents where dissolved oxygen was detected, the levels were found ranged between 0.2mg/l in paint 'C' to 5.5 mg/l in matchstick company in the dry season whilst in the wet season the values ranged from 0.13mg/l in brewery 'B' to 9.64 mg/l in matchstick company. Interestingly, in matchstick the dissolved oxygen was noted to be highest reaching the

saturation levels of dissolved oxygen in natural water of 9.0mg/l at 25⁰ C. This is due to the use of potassium dichromate ($K_2Cr_2O_7$) and potassium chlorate ($KClO_3$) solutions that are pasted onto the matchstick head to supply oxygen needed for combustion. The solutions end up in wastewater from both the production line and laboratory where they are mixed. The effect of potassium chlorate and potassium dichromate on dissolved oxygen levels in matchstick effluent suggests that chemical waste can impact the quality of wastewater both positively and negatively as such looking at one parameter as a pollution indicator can be misleading. Whilst potassium dichromate contributes greatly to the chromium levels in the wastewater from matchstick productions, the same salt increases dissolved oxygen levels. Probably what would matter is the net effect of the constituents in the wastewater onto the environment.

It is worthwhile to mention that temperature's effect on DO was evident in effluents from battery industry where DO was not detected in both season with temperatures of high as 71⁰C and 100⁰C .This observation showed that apart from organic loading, the temperature of water might have influenced the amount of dissolved oxygen present since less oxygen dissolves in warm water than cold water (NGRDC, 2005).

Pearson correlation showed that BOD in the dry season had significant negative impacts on the DO level with Pearson correlation of -0.312 and p value of 0.004 which was significant at $\alpha = 0.01$. Although COD levels contributed negatively to the amount of Dissolved oxygen in the wastewater in the same period (Pearson correlation factor of -0.057), the impact were not significant ($p = 0.604$). This observation confirms the fact that organic matter in the water can lead to depletion of oxygen. In the wet season however, there was no strong evidence of the samples void of oxygen being caused by levels of BOD and COD ($p > 0.05$). If effluent with high BOD and COD levels is discharged into a stream or river, it will accelerate bacterial growth in the river and consume the oxygen levels in the river. The oxygen may diminish to levels that are lethal for most fish and many aquatic insects.

The Blantyre City Assembly sets a minimum of 1.0mg/l as threshold level for compliance and table 3.1 gives the list of companies that complied in this study. From the table, the compliance of some companies to the set minimum limit varied greatly between season probably due to variation in industrial activities and in-house activities on effluent management.

Table 3.1: DO levels of industries that complied with the BCA discharge limit

Industry	Dry season DO (mg/l)	Wet season DO (mg/l)
Abattoir A	ND (Not Detected)	2.11
Brewery A	3.00	2.0
Bottling	2.6	2.54
Chemical	ND	2.14
Confectionery	ND	1.86
Dairy B	ND	1.08
Edible Oil B	1.30	1.35
Match	5.50	9.64
Motor Oil B	2.00	1.66
Petroleum refinery B	2.3	1.20
Pharmaceutical	1.40	4.02
Printing A	ND	2.91
Printing B	1.80	1.17
Textile D	2.40	N/A
Blantyre City Assembly limit	>1.00	>1.00

KEY: ND means Not detected

3.1.9 Suspended solids in industrial effluent

Suspended solids (SS) are solids in water that can be trapped by a filter. The solids include a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes and sewage.

Effluents from this study exhibited levels of suspended solids ranging from 5.07 ± 0.04 mg/l in petroleum storage B to 3320.09 ± 31.04 mg/l in chemical industry in the dry season (Appendices 3&4). Statistical analysis by ANOVA at 95% confidence interval showed that the levels of suspended solids differed significantly from each other ($p=0.00$) except effluents from a pair set of abattoir B and textile C, motor oil A and printing A, and paint 'A' and abattoir 'B' which did not significantly differ. The mean levels of suspended solids were significantly higher than the mean levels in the wet season ($p=0.000$, Independent t test).

There is no discharge limit on suspended solids for Blantyre City Assembly, but comparing the levels exhibited by industries against the public sewer discharge limits in Nepal (600mg/l), India

(600mg/l), Singapore (400mg/l) and Cape Town (1000mg/l), a good number of industries exceed the limits. However most notably are those that are exceeding the Cape Town limit which include industries like edible refinery oil A (1203.05 ± 24.03 mg/l), motor oil A (1800.50 ± 15.06 mg/l) and printing 'A' (1776.10 ± 7.89 mg/l) which may be greatly be due to the fact that their effluents contains oily wastes.

In the wet season the high levels of suspended solids ranged between 4.02 ± 0.01 mg/l in motor oil B and $71,490.0 \pm 400.0$ mg/l in edible refinery oil A. The levels of suspended solids differed significantly from each industry (ANOVA, $p < 0.05$) except effluents from brewery 'A' and matchstick manufacturer. In the wet season, levels higher than discharge limits in Nepal, Singapore and India were observed at matchstick (650.88 ± 14.24 mg/l), brewery 'A' (725.01 ± 7.04 mg/l) and printing 'B' (834.20 ± 16.02 mg/l) whilst chemical industry (1325.55 ± 25.50 mg/l) and edible oil refinery B exceeded the Cape Town limit.

The high levels observed could be attributed to oils, silt and solids waste that find their way into the effluent channels or sometimes in effluent holding tanks. High concentrations of suspended solids can cause many problems for stream health and aquatic life. In addition high-suspended solids can block light from reaching submerged vegetation thereby slowing photosynthesis. In addition they can also cause an increase in surface water temperature, because the suspended particles absorb heat from sunlight, which ultimately reduces, dissolved oxygen levels.

The observation made in this study of industries that discharged effluents with suspended solids exceeding the discharge limits agrees with the study by Emongor et al, 2005 on industrial effluents in Gaborone, Botswana which showed some industries like brewery, chemical and paints exceeding the local authority maximum limit of 1000mg/l. The study of Emongor et al recorded the highest value being 2069 mg/l brewery, whilst in this study the highest level were observed at 71,490 mg/l in edible oil refinery. The big difference is obviously to the nature of the effluent; whereas suspended solids in effluent from the brewery is mainly characterised by dregs, the effluent from edible plant being referred herein is mainly oil waste.

3.1.10 pH and alkalinity of industrial effluents

The results in the appendices 3 and 4 indicate that pH of the industrial effluents in the dry season ranged from 3.5 for dairy B to 10.6 for paint industry A. The other low pH values were observed at breweries A and B which registered 4.1 and 4.3 respectively. The pH observed in these industries was too low that they can influence metal toxicity. On the other hand, higher pH value of 10.2 was also observed at bottling company. The results for the wet season showed the effluents from a edible oil refinery A and brewery A being acidic at as low as 3.0 and 3.9 respectively whilst brewery B and bottling company showed alkaline effluent of as high as 12.0 and 10.7 respectively.

The city byelaws recommend the pH range of between 6.5-9.5 for effluents being discharged into the public sewer lines and streams. This therefore infers that some industries like bottling, brewery, dairies, and paint, and vegetable cooking oil, confectionery discharge effluents with pH exceeding the limits set by the local assembly (appendices 3 & 4).

The observed levels of pH in brewery industry are in agreement with the study of effluent done on three industries in Lilongwe, Malawi where two breweries had registered low levels of 4.2 and 5.2 in dry season and levels of 4.8 and 4.2 in wet season (Phiri et al, 2005). Apart from the suggestion made by Phiri et al that the low pH levels in the effluent from breweries could be due to the raw materials such as corn, sorghum, enzymes, lactic acid and yeast that are used by industries, the acidic effluents observed in brewery industry and others may also be due to usage of acids like nitric acid and sulphuric acid. Nitric acid is commonly used for cleaning the production line between each batch and sulphuric acid is used for lowering the pH in wastewater treatment in edible oil industry. The higher pH could be attributed to the use of caustic soda for washing packaging bottles as well as production machinery.

Alkalinity is the capacity to neutralize acids and the alkalinity of natural water is derived from salts of weak acids. Alkalinity itself has little public health significance but in streams and rivers, it can alter the pH values resulting in a break in the natural buffer system (Bhatia, 2003). Most of the industries under this study showed significant levels in total alkalinity (figure 3.7).

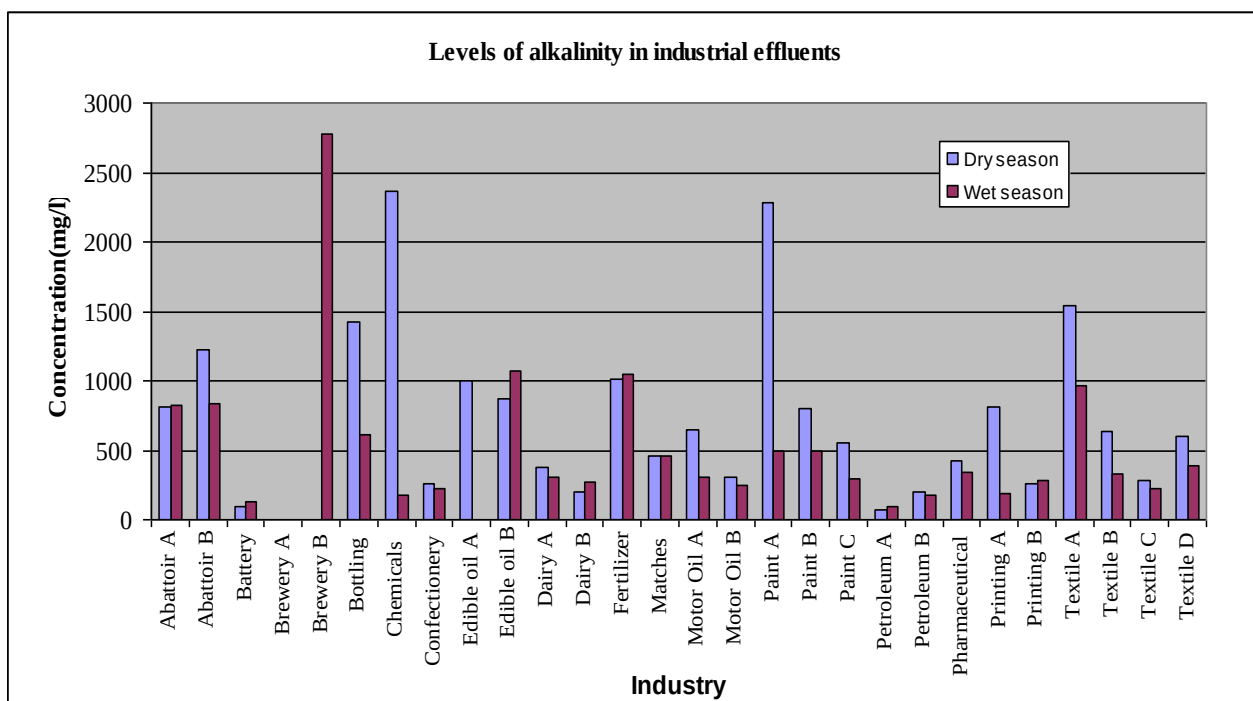


Figure 3.7: Levels of total alkalinity in industrial effluents

The levels of total alkalinity in the wet season were found to range from below detectable levels in brewery 'A' and edible oil refinery 'A' to 2780 mg/l in brewery 'B' whilst in the dry season the values ranged from 0.0mg/l in brewery 'A' and 'B' to 2370mg/l in chemical industry. The mean levels of alkalinity in the dry season were significantly higher than the wet season results with p value of 0.049 (Independent t test, $\alpha=0.05$). Alkalinity concentrations in the dry season differed significantly among the industries ($p=0.000$, ANOVA), however the effluents from pairs of both breweries ($p=1.00$), confectionery and printing industry B ($p=0.770$) and dairy B and petroleum depot B did not differ significantly from each other. The trend was almost the same in the wet season where the levels of total alkalinity in the industrial effluents differed significantly ($p=0.000$) except pairs of brewery A and edible oil A (1.000), chemicals and petroleum depot B ($p=0.348$), and dairy A and motor oil A ($p=0.170$)

Alken Murray Corporation, 2003, has defined alkalinity as the sum of components (mainly bicarbonates, carbonate and hydroxide) in the water that tend to elevate the pH of water above 4.5. As shown in figure 4.3, the bars for brewery industry in the dry season is non-existent because both breweries ($\text{pH}<4.5$) had registered 0.0mg/l of alkalinity. The direct relationship of alkalinity and pH was further confirmed in this study through Pearson correlation in both seasons where it showed strong correlation at $\alpha = 0.01$ with p values of 0.000 and positive Pearson

correlations of 0.721 and 0.750 in the dry and wet seasons respectively. However regression analysis showed that the levels of alkalinity influenced 51.9 % of the pH levels observed in the dry season and 56.3 % in the wet season. Alkalinity together with phosphates levels were also observed to directly impact the levels of pH in both the dry season ($p=0.003$, $r^2 = 0.57$) and wet season ($p=0.000$, $r^2= 0.72$).

The use of caustic soda (NaOH) for washing of mixing drums and packaging materials together with high levels of phosphates and ammonium could have contributed to the total alkalinity levels found in these industries.

3.1.11 Levels of oil and grease in industrial effluents

Water immiscible liquids may be present as fat, oil and grease and most often in the form of emulsions. This group of oils is generally lighter than water and usually spreads over the surface to form thin film that even in small quantity is likely to pollute a large area. In the wet season , the levels of oil and grease in the effluents ranged from 1.30 ± 0.0 mg/l in abattoir 'A' to 223.79 ± 9.02 mg/l in edible oil refinery A whilst in the dry season the levels ranged from 2.34 ± 0.02 mg/l in abattoir 'B' to 650.00 ± 4.00 mg/l in edible oil refinery A(appendices 3&4). However the mean levels of oils between the season did not differ significantly at $\alpha =0.05$ ($p=0.121$, Independent t test).

In both seasons the oil levels in the effluents differed significantly among them with p values of 0.000 in both periods of study (ANOVA, 95% CI) probably due to different industrial activities. For example in motor oils the oil spills result from car washing and maintenance whilst in edible oil refineries the fatty matter emanates from product waste. The ability of oil interceptors in removing the waste might have also contributed to the big variations of oil levels in the industrial effluents. Nevertheless in each season some industries registered insignificant oil levels that did not differ from the others. In the dry season effluents from abattoir B and paint C ($p=0.104$) did not differ significantly whilst in the wet season A similar observation was made on pairs of confectionery and dairy A ($p=0.130$) and, paint B and edible oil B ($p=0.814$).

Although literature indicates that oil in water affects dissolved oxygen, this study did not find the inverse relationship of these parameters significant at $\alpha=0.05$ although the impact was negative (Pearson correlation -0.167, $p=0.129$). However some sampling points like edible oil A which

registered high levels of 223.79 mg/l in the wet season and 650.00 mg/l in the dry season had registered 0.0 mg/l dissolved oxygen. This therefore suggests that the negative effects of oils on dissolved oxygen may largely be determined by amount of oil and grease in water other than generalisation of the effects at any levels.

The Blantyre City Assembly discharge limit into the public sewer for oil and grease is 10mg/l. It is clear therefore from table 3.1a & 3.1b and 4.3 that a small proportion of companies complied with this limit. If the effluent limits were flexed to the tolerance limit set by Cape Town (400mg/l) and typical tolerance limits for India of 100mg/l, edible oil refinery 'A' would still exceed both limits in the dry season (650 ± 4.00 mg/l) whilst in the wet season it only exceeds the limit for India.

Table 3.2: Industries that complied with Oil and Grease discharge limit

Industry	Oil & Grease (mg/l)	
	Wet season	Dry season
Abattoir A	1.30 ± 0.0	6.10 ± 0.035
Abattoir B	7.85 ± 0.98	2.34 ± 0.21
Dairy A	AL	5.30 ± 0.00
Dairy B	AL	3.31 ± 0.09
Petroleum Refinery A	6.17 ± 0.38	1.11 ± 0.01
Petroleum Refinery B	6.71 ± 0.40	2.19 ± 0.04
Printing A	AL	6.39 ± 0.03
Printing B	AL	2.44 ± 0.03
Blantyre City Assembly limit	10	10

KEY: AL stands for above the limit

In this study 50% of the industries are considered to be the ones likely to discharge effluent containing oil, fat and grease. The compliance of these industries on levels of oil and grease varied greatly with seasons and activities of the industry within a specific period.

As stated by Porteous, 2000 that the presence of an oil film with thickness of only one thousandth of a millimetre ($1\mu\text{m}$) may reduce the rate at which oxygen is transferred from air to water, there a need therefore for industries to reduce the oil and grease levels to safe concentrations that will not same impair the water quality of streams in streams should if the effluent of this kind are discharged into water bodies.

Oil and grease in effluent emanating industries could be attributed to the fatty matter in dairy industry resulting from spillages and discarded milk products, washings from the production machine between each batch. In the other industries like petroleum depots, oil and grease comes from spillages of petrol, diesel when petroleum tankers dispatches off the products and spent water from car washing. In printing industry the oil results from washings of printing rollers, which are usually cleaned with turpentine whilst in motor oil which in essence are garages, the oil and grease comes from spent water after washing of automobiles and their engines after maintenance. In confectionery plants the oil is due to water cleaning of flying pans, which is more often full of cooking oil waste. The high levels observed in edible oil refinery industry 'A' could be attribute to the cooking oil waste that goes through a derelict effluent treatment plant.

3.1.12 Levels of metals in industrial effluents

The ramifications of heavy metals in the environment can be adverse because through the natural process of biomagnification, minute quantities of metals become part of the various food chains and concentrations become elevated to levels, which can prove to be toxic to both human and other living organisms (Fatoki, 2001). The results of metals and nutrient calcium and potassium levels in both seasons of study are shown in appendices 5&6.

3.1.12.1 Cadmium

The levels of cadmium ranged between $0.002 \pm 0.0\text{mg/l}$ in paint industry 'A' to $0.060 \pm 0.005\text{mg/l}$ in abattoir A industry (appendices 5&6). The other industries that exhibited cadmium levels are given in table 3.3.

Table 3.3: Levels of cadmium in industrial effluents (Dry season)

No	Industry	Cadmium mg/l
1	Printing A	0.025 ± 0.002
2	Printing B	0.034 ± 0.001
3	Textile B	0.028 ± 0.004
4	Textile C	0.034 ± 0.003
5	Motor oil B	0.025 ± 0.004
6	Fertilizer	0.019 ± 0.001
7	Battery	0.019 ± 0.001
8	Edible oil refinery B	0.014 ± 0.002
9	Dairy B	0.015 ± 0.001

The levels of cadmium in the abattoir effluent differed significantly with the rest of the industries at 95% confidence interval ($p=0.000$, ANOVA) whilst the effluent from battery did not differ significantly with effluent from fertilizer ($p=1.000$), the same applied to edible oil 'B' and dairy 'B' ($p=0.391$), motor oil 'B' and printing 'A' ($P=1.000$), and printing 'B' and textile 'C' ($P=1.000$). In the wet season, cadmium was not detected in all the samples probably due to dilution effect. The presence of cadmium as observed in the dry season could be attributed to the fact that cadmium is a common ingredient in various pigments and coatings. Further, it is an impurity in salt, caustic or soda ash used in processing; furthermore fertilizer is a natural sink of cadmium element (BSR 2002).

When compared with discharge limits set by India of 2mg/l, the levels of cadmium in these industries are significantly below the limit. In Malawi's setting the discharge limit for cadmium should be less than 0.05mg/l because of poor technological wastewater treatment which may not effectively reduce cadmium to safe levels. If such a situation arises then it could be harmful to the human health of primary user of the water downstream where they depend on untreated water sources like streams.

3.1.12.2 Chromium

The results showed that it is the only effluent from matchstick industry that exhibited high levels of chromium in both seasons. The levels were observed to be as high as 41.59 ± 0.46 mg/l in the dry season and 56.12 ± 1.12 mg/l in the wet season. Using Man -Whitney statistic test at 95% confidence interval the levels of chromium between the two phases differed significantly ($p=0.019$). The difference is probably due to the seasonal or daily variation in activities of the industry. The presence of chromium is due to the use of potassium dichromate ($K_2Cr_2O_7$) as a raw material for producing match heads, which when combined with potassium chlorate ($KClO_3$) are used to supply oxygen needed for combustion (Kristine and Jacqueline, 2006)

Although Blantyre local assembly as an authority did not set any limit on metals, the values of chromium in this industry far exceeds the limits set by most local assemblies worldwide as recommended by Bhatia (2003) which is normally 2mg/l. Although the effluent from matchstick is not directly discharged into the natural water bodies, the levels observed at matchstick industry calls for proper management of the waste otherwise if this kind of effluent were discharged directly into the stream, the effects associated with chromium would be adverse because known

health effects from ingesting water contaminated with chromium (trivalent or hexavalent forms) at levels above the drinking water standard (child: 0.2 mg/L, 1 L/day for 7 years) may include liver and/or kidney damage, harm to the circulatory system and nerve tissue, as well as dermatitis (BSR 2002).

3.1.12.3 Copper

Levels of copper in the industrial effluents under study ranged from 0.026 ± 0.013 mg/l in battery industry to 2.00 ± 0.01 mg/l in paint 'C' industry (Figure 3.8).

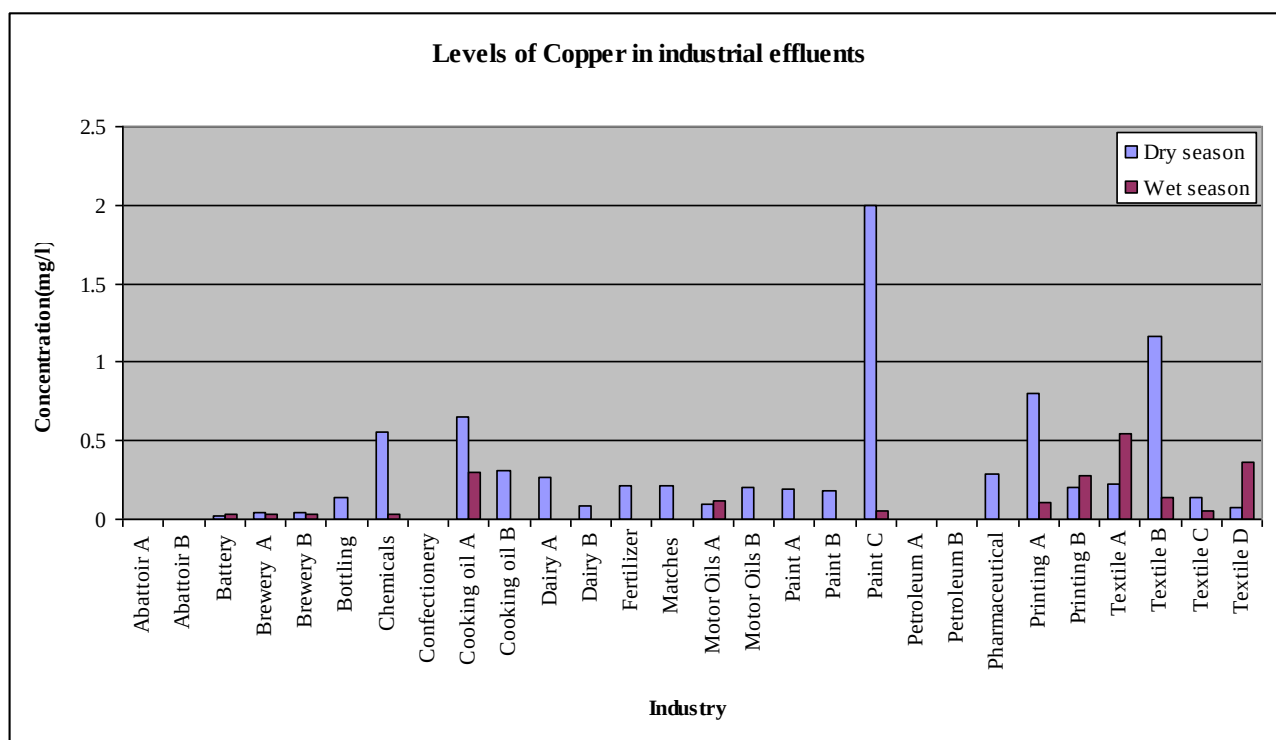


Figure 3.8: Levels of copper in industrial effluents

As shown in figure 3.8, levels of copper were noted in both seasons in battery, brewery, chemical, motor oils, edible oil, paint, printing and textile industries. The levels between each category of industry differed significantly using both ANOVA ($p=0.00$) and Kruskal Wallis ($p=0.001$) at 95% confidence interval. However the levels did not differ significantly in battery, brewery and confectionery ($p=0.192$) likewise in effluents from fertilizer, matchstick and motor oils ($p=0.630$).

The results on copper levels in all industries are significantly below the tolerance limit of 3mg/l as suggested by India sewer tolerance limit. The presence of copper in these industrial effluents

could be attributed to the fact that copper and its compounds are used in many different aspects of textile and apparel manufacturing. In textile industries the metal can be found in some form in dyes, nylons, textiles as well as fungicides, pesticides and herbicides (BSR, 2002). In the printing, the blue print commonly used is produced from pigments that contain copper (Ackermann, 2001). Similarly in paint industries copper is another important ingredient in pigmentation of the paint products. This probably is the reason why in this study copper levels were relatively high in industries with pigmentation of products like textile, printing and paints. In motor oils, which are mainly garages, the copper contaminant might have come from scraped metals and pigments drop offs from motor vehicles. In the other industries the source of copper could be from plumbing materials, effluent holding tanks and of course copper may also exist in the incoming process water.

3.1.12.4 Iron

This study has shown that levels of iron were detected in industrial effluents (Figure 3.9).

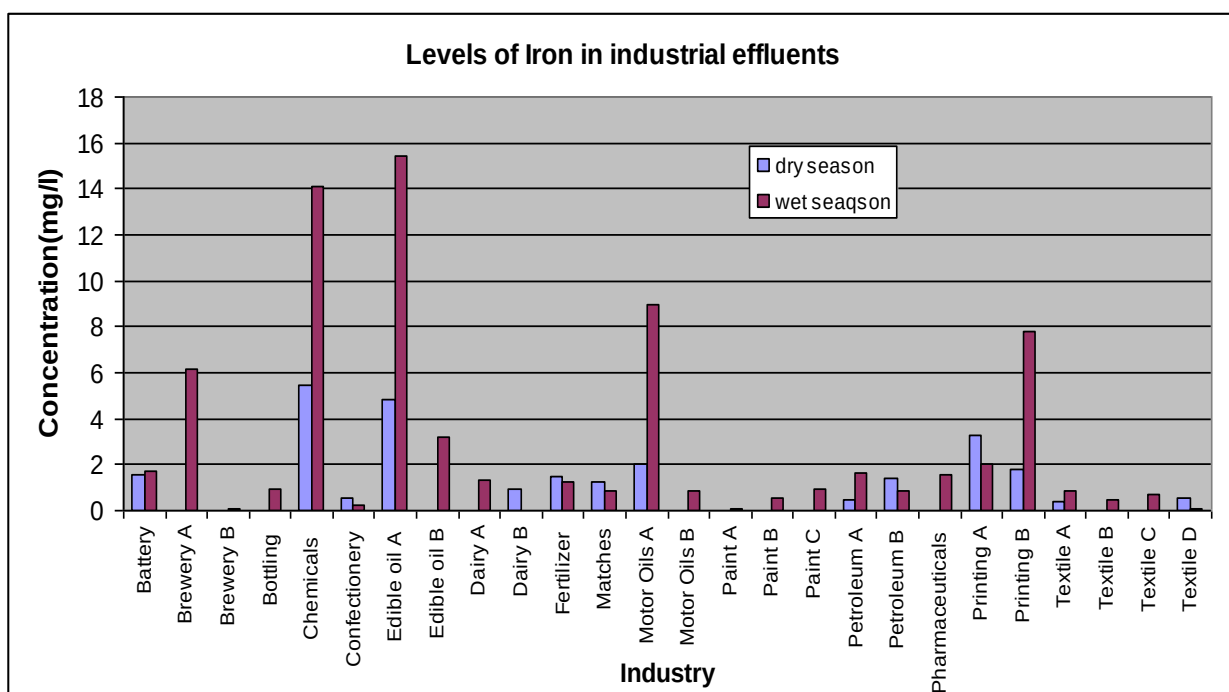


Figure 3.9: Levels of Iron in industrial effluents

The iron levels in effluent ranged from 0.41 ± 0.15 mg/l in textile A to 5.48 ± 0.92 mg/l in chemical industry in the dry season. In the wet season the levels varied from 0.074 ± 0.03 mg/l in textile D to 15.44 ± 0.36 mg/l in edible oil refinery A. Other categories of industries that

registered high iron levels in the wet season were chemical ($14.08 \pm 0.03\text{mg/l}$), motor oil ($8.996 \pm 0.001\text{mg/l}$) and printing ($7.80 \pm 0.47\text{mg/l}$). In the dry season apart from the chemical industry registering high levels of iron, the other industries that followed it includes edible oil refinery A ($4.80 \pm 0.42\text{mg/l}$) and printing ($3.25 \pm 0.10\text{mg/l}$).

Although iron is one of the natural water contaminant, which could account for the traceable levels observed in the some of the industrial effluents, in the industries that registered relatively high levels, the iron results from rusting of the treatment plant material and sewer pipes whilst in industries, abattoirs in particular, iron in the blood of carcasses contributes to the observed iron content in the effluent. Iron levels observed in chemical manufacturers and printing industries could be due to the fact that iron and its compounds are used in pigmentation of the products because all iron oxides possess good tinting strength and excellent hiding power (Buxbaum et al, 2006).

The levels of iron in the industries differed significantly from each other in both the wet season ($p=0.010$) and dry season ($p=0.011$). However the levels of iron in all industries were observed to be within the limit set by Cape Town effluent discharge limit of 20mg/l . Generally the levels were relatively higher in wet season than dry season probably due to massive washing of iron salts and compounds by the rains since most of the pre-treatment and effluent holding tanks are usually in the open.

3.1.12.5 Manganese

In this study the levels of manganese in the industrial effluents in the dry season were noted to be in traceable amounts (Figure 3.10), which ranged from $0.083 \pm 0.015\text{mg/l}$ in dairy A to $1.458 \pm 0.100\text{ mg/l}$ in edible oil refinery 'A' whilst in the wet season the values ranged from $0.001 \pm 0.0\text{ mg/l}$ in textile C to $9.01 \pm 0.15\text{mg/l}$ in battery company. In some of the industries under study manganese was not even traced (figure 3.10)

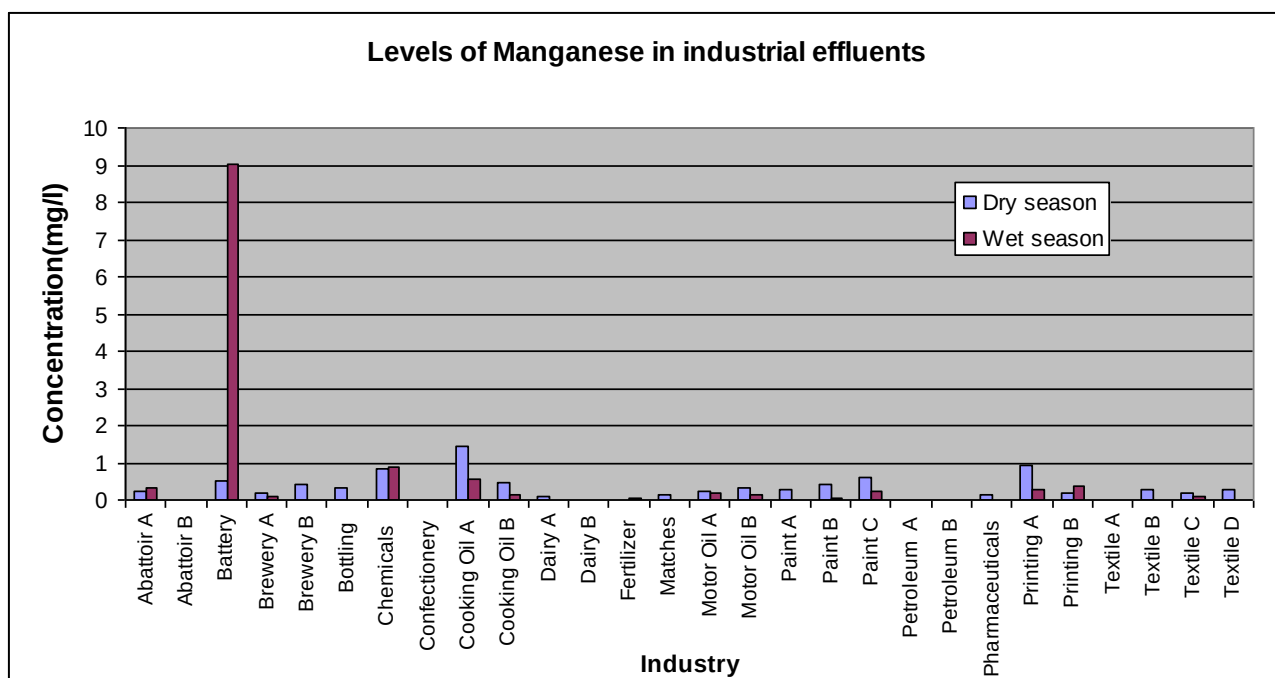


Figure 3.10: Levels of Manganese in industrial effluents

The levels of manganese in the industrial effluents where it was traced differed significantly at 95% confidence interval in both dry and wet season where p values were 0.009 and 0.004 respectively.

The traces of manganese in most of the industries could be attributed to usage of manganese compounds which are used in small amount whilst manganese levels which were highest in effluent from battery industry ($9.01 \pm 0.15\text{mg/l}$) in both phases of study could be due to spillages of manganese dioxide that forms part of the white paste that function as cathode in a dry cell. Like calcium and potassium, there are no discharge limits set for this parameter by all local authorities that are being referred to in this study.

3.1.12.6 Zinc

Although zinc is an essential element in human growth, in concentrations over 5mg/liter it can make water cloudy and bitter tasting, and can even be toxic in large quantities (BSR, 2002). The results for the concentrations of zinc in industrial effluents are provided in figure 3.11.

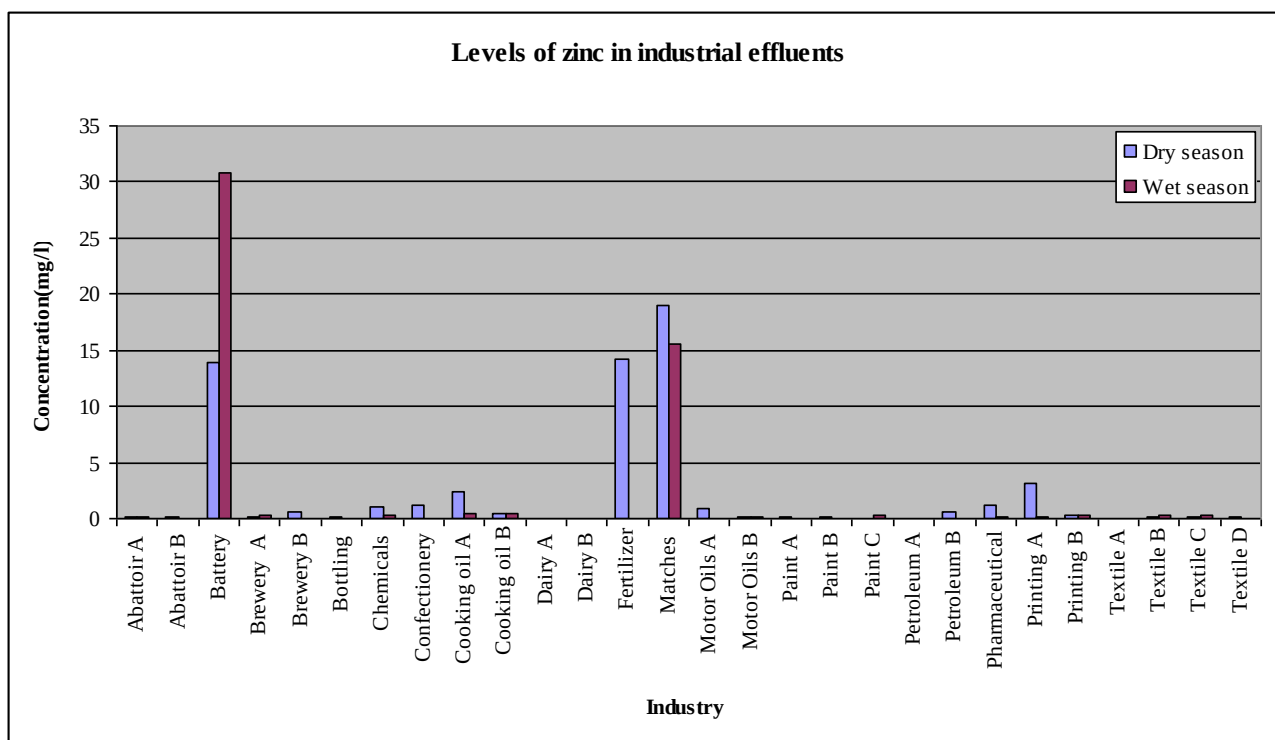


Figure 3.11: Levels of Zinc in industrial effluent

As displayed in figure 3.11, the levels of zinc in industrial effluent in most of the industries under study showed traceable amounts. In the wet season the levels of zinc in industrial effluents ranged from 0.012 ± 0.0 mg/l in motor oil 'A' to 30.83 ± 1.00 mg/l in battery manufacturer. Effluent from matchstick was found to produce levels of zinc as high as 15.51 ± 4.50 mg/l. In the dry season the levels of zinc in the industrial wastewater were found to lie between 0.07 ± 0.01 in edible oil refinery A to 18.97 ± 0.01 mg/l in matchstick production. The other industries that produced significant levels of zinc include battery (13.9 ± 0.46 mg/l) and fertilizer (14.4 ± 0.25 mg/l).

The levels of zinc in the industries differed significantly in the wet season ($p=0.019$) as well as in dry season ($p=0.009$). However the mean level of zinc in the dry season did not differ significantly from the mean levels of wet season ($p=0.920$, Independent t test).

Using the tolerance sewer discharge limits of 15mg/l set by India, the levels of zinc in battery and matchstick effluents in the wet season far exceeds the limit whilst in the dry season the levels of zinc in matchstick industry is above the permissible limit. If the same quality of effluent is measured against the limit of 30mg/l set by Cape Town, only the battery industry exceeds the limit.

The pronounced presence of zinc in the industrial effluents from battery, matchstick and fertilizer could be attributed to use of zinc salts. In the battery company zinc chloride serves as the cathode together with manganese dioxide and carbon in dry cells. In matchstick production, zinc oxide is added to the tip of the matchstick to give it a whitish colour whilst in fertilizer industry zinc sulphate is usually used as a raw material to supply the needed amount of zinc during production of dry fertilizer materials (Rehm and Schmitt, 2002).

3.1.12.7 Lead

There is overwhelming information that shows that lead produces adverse effects on living organisms; it is never essential or beneficial. Lead is toxic in most of its chemical forms and can be incorporated into organisms by a number of pathways (inhalation, ingestion, skin contact, absorption)

Levels of lead in the dry season were observed in following industries; chemical (0.143 ± 0.0 mg/l), edible oil refinery A (0.143 ± 0.0 mg/l), paint 'A' (1.22 ± 0.65 mg/l), paint 'B' (1.29 ± 0.0 mg/l), printing 'A' (0.286 ± 0.0 mg/l) and printing 'B' (2.60 ± 0.02 mg/l). The levels of lead in chemical and edible oil refinery A did not differ significantly from each other ($p=1.000$, ANOVA). In the wet season, effluents from matchstick (0.465 ± 0.07 mg/l) and printing industry B (0.233 ± 0.0 mg/l) exhibited levels of lead in their effluents. The lead levels among the industries differed significantly in both the dry season ($p=0.006$) and wet season ($p=0.013$) except effluent from chemical and edible oil refinery 'A'. In the wet season the levels were far much lower than levels in dry season. This could be due to dilution effect as a result of the rains since most of the treatment systems are located in the open without proper coverage. It could be also due to the fact that lead was removed by hydroxides because at pH 6.3, lead hydroxide flocculants are formed and are easily separated by sedimentation together with other suspended solids (PPMA, 2006). This observation could be also due to the complexity and variation of industry effluent quality, which can differ hourly, daily and seasonally because industrial effluent is usually intermittent other than 'batch' as such it may be that at the time of sampling the water paint which usually contains lead was not being produced.

The lead results in the dry season from paint and printing industries exceed the industrial discharge limit of 1.0 mg/l by India discharge limit on public sewer whilst the levels in matchstick and chemicals exceed the Nepal permissible limit of 0.1mg/l in the wet season. If the

levels are compared to the trade effluent byelaws of Cape Town of 5mg/l permissible limit then none of the levels noted in this study exceeds the limit.

The lead levels observed could emanate from different sources in different industries. In the printing and paint companies of Blantyre lead is a common additive that is used as a catalyst for polymerization of paint and printing ink (Chirwa, 2006). Lead finds its way into the industries because of its use as pigment, dispersing agent and drying agent. In matchstick lead oxide is used to give the scarlet colour of the match head (Kristine et al, 2006). The study done by Henry and Kalua (2001) revealed that edible oils which are produced in Blantyre have high levels of lead (6.5-12.0 mg/l), probably this is the source of lead observed in effluents from edible oil refinery A (0.143mg/l) in the dry season .

The study has supported the former studies which inferred that lead contamination of streams in Blantyre city emanated from industries. The only difference is that most probable source for lead contamination in the previous studies was on vehicular emissions and leaded petrol (Lakudzala et al, 1999, Mvuma, 1995 and Sajidu et al, 2006) whilst this study has shown that effluent from printing, paint, chemical and matchstick industries are equally potential sources of lead.

3.1.12.8 Nickel

Levels of nickel were observed in industrial effluent from abattoir 'A' (0.222 ± 0.0 mg/l), chemical (0.222 ± 0.001 mg/l) and edible cooking oil 'A' (1.11 ± 0.31 mg/l) in the dry season whilst in the wet season nickel was noted in abattoir 'A' (0.383 ± 0.014 mg/l) and textile 'B' registered 0.07 ± 0.01 mg/l (appendices 5 and 6). At $\alpha = 0.05$, ANOVA test shows that the levels of nickel in the effluents for dry season differed significantly ($p=0.00$) except for abattoir A and chemical industries (ANOVA, $p=0.993$) whilst Mann Whitney test showed significant difference in the effluent from industries in the wet season ($p=0.019$). However the levels of nickel are below the permissible limit for industrial effluent discharge into the sewer against the Cape Town limit of 5mg/l and typical sewer effluent discharge limit of 2mg/l in India.

The presence of nickel could be attributed to the fact that nickel and its compounds are sometimes used in manufacturing of dyes. Thus it may appear as impurities in inputs rather than as a component of materials used in various industrial productions and processing (BSR, 2002).

This could be true for Malawian industries where majority of raw materials used in industries are best known by their brand names other than chemical names.

The findings on abattoir effluent containing nickel are in line with a study performed by Petaluma in infeasibility analyses of city of American canyon wastewater treatment and reclamation facility showed that food processors and bottlers might discharge nickel from their food-processing machine cleaning operations (CACWTRF, 2006). In the effluents from abattoirs, the levels might have been aggravated by nickel in stock feeds that had biomagnified in the slaughtered cattle.

3.1.12.9 Potassium and Calcium in industrial effluents

Potassium and calcium are one of the important cations that significantly change the chemical composition of water when present in concentrations above or below biologically tolerable levels (SETAC, 2004).

Figures 3.11 and 3.12 give the concentrations of potassium and calcium in industrial effluents. In both periods of study the least levels of potassium were observed in industrial effluent from petroleum refinery 'B' which registered $4.59 \pm 0.04\text{mg/l}$ and $2.34 \pm 0.15 \text{ mg/l}$ in dry and wet seasons respectively whilst matchstick registered the highest levels of $20.47 \pm 0.0 \text{ mg/l}$ in dry season and $20.00 \pm 0.0 \text{ mg/l}$ wet season.

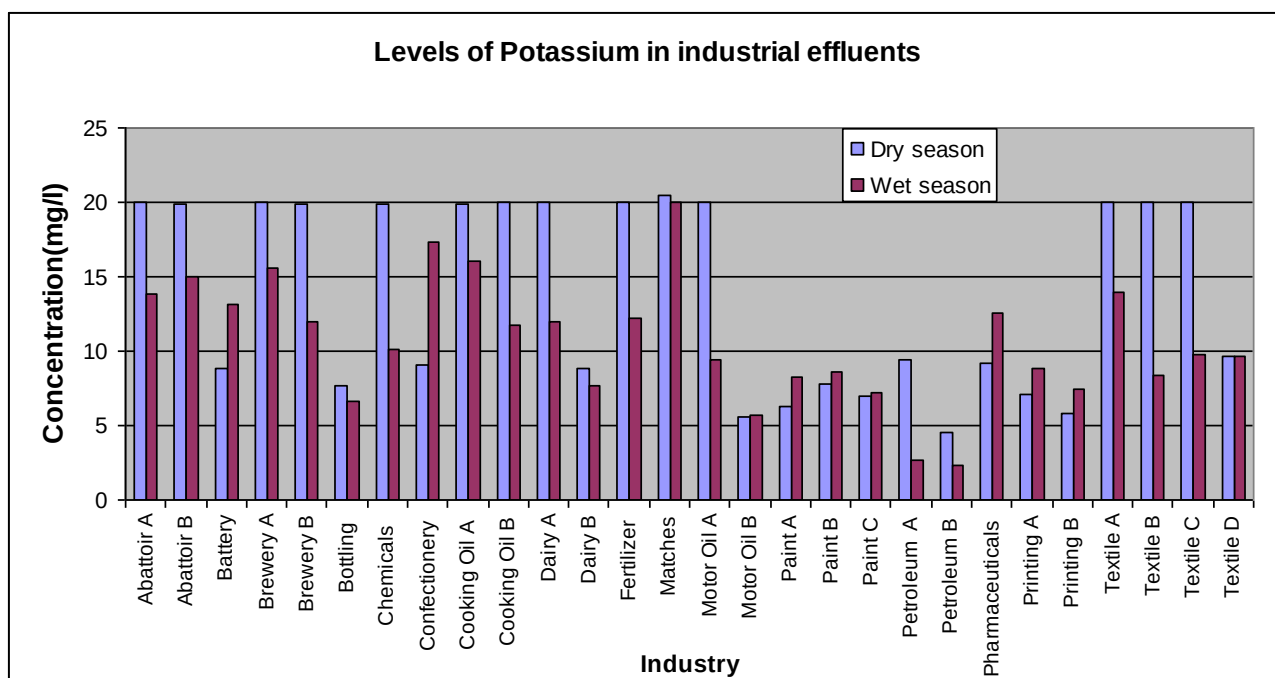


Figure 3.11: Levels of potassium in industrial effluents

As shown in figure 3.11, the maximum levels of potassium in these industrial effluents varied greatly between the seasons with the dry season levels being generally higher than values in the wet season values probably due to dilution effect. In the dry season potassium levels in matchstick differed significantly ($p=0.00$) from the rest of the industries but effluents from abattoir, brewery, chemical, dairy, edible oil refinery, textile, fertilizer and motor oil did not differ significantly ($p>0.05$). In the wet season the levels of potassium differed significantly in among the industries ($p=0.00$, ANOVA).

Potassium occurs naturally in water and this may account for some of the minimal levels of potassium observed in some of the industrial effluents. However the exacerbated levels in most of the industries as depicted in figure 3.11 could be attributed to the fact that potassium is mainly used in fertilizers production and it is this fertilizer that eventually ends up in some of the raw materials used in food industries like brewery where they use raw materials like sorghum and maize which absorb potassium from the soils. Potassium salts are also common in industries because they are used in different forms. For example, potassium hydroxide is used to make liquid soaps and detergents and little potassium chloride goes into pharmaceuticals, medical drips and saline injections whilst other potassium salts are used in baking and for making iodize salts (Lenntech, 2006). In the matchstick, they use quite a lot of potassium dichromate and potassium chlorate (Nyanyula, 2006) that supply oxygen for combustion. In all cases it is the

negative anion, not the potassium, which is the key to their use (lenntech, 2006). Potassium can be found in vegetables, fruit, potatoes, meat, bread, milk and nuts hence the presence of potassium in most of the effluents under study.

Calcium is a naturally occurring element and, along with magnesium, is responsible for the degree of water hardness (SATEC, 2004). The levels of calcium in this study in the effluents ranged from 6.65 ± 0.08 mg/l in edible oil refinery 'A' to 83.06 ± 0.33 mg/l in paint 'B' in the dry season whilst in the wet season the levels were found to lie between 2.47 ± 0.17 mg/l in confectionery and 53.88 ± 0.17 mg/l in pharmaceutical industry (figure 3.11).

Generally the levels of calcium varied greatly from industry to industry probably due the differences in industrial activities. Using ANOVA at 95% confidence interval, the concentrations of calcium in the dry season differed significantly ($p=0.000$). However, there were no significant differences in levels of calcium in abattoir, chemical, matchstick and textile ($p>0.05$). Similarly there was no significant difference in mean levels of effluents from battery, dairy and motor oils ($p>0.05$) and the same applied to printing and textile ($p=0.108$).

In the wet season the levels of calcium also differed significantly from industry to industry ($p=0.000$) except for the following industries whose effluent did not differ significantly: brewery and bottling ($p=0.293$), dairy, motor oil and edible cooking oil ($p>0.05$), fertilizer and pharmaceuticals ($p=0.088$), printing and textile ($p=0.093$). There are no discharge limits set for calcium by local authorities since calcium is regarded as an essential element.

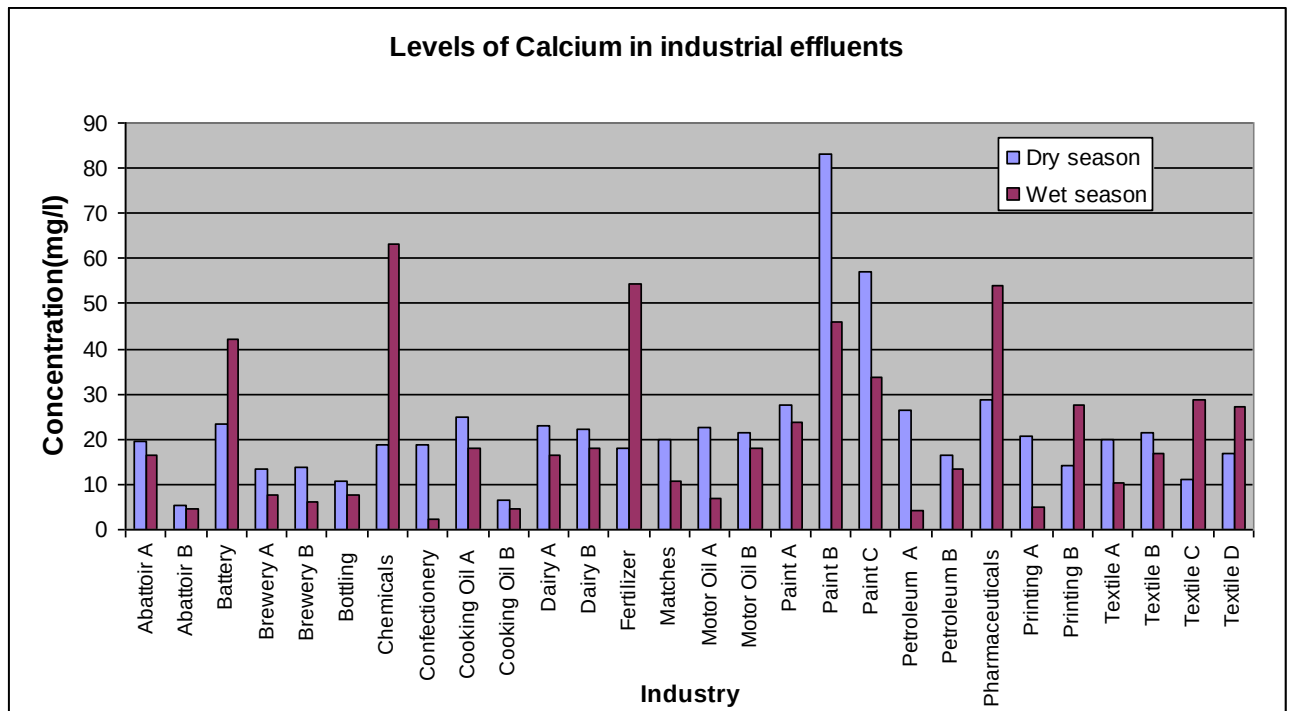


Figure 3.12: Levels of calcium in industrial effluents

Apart from the fact that calcium is a natural occurring element in the water, milk and nuts, the apparent observed high levels in industries like pharmaceuticals could be attributed to the fact that calcium is an active pharmaceutical ingredient whilst in fertilizer industry gypsum, a raw material that contains calcium is extensively used. Calcium is also an important additive used in paint as a surface drying agent hence the high levels of calcium in paint industry (Chirwa, 2006). In addition calcium hypochlorite is used as a bleaching powder for dyeing and finishing in textile and laundries (ILO, 2000).

3.2 QUALITY OF WATER IN STREAMS PASSING THROUGH INDUSTRIAL AREAS

The results of water quality of streams that pass through the industrial areas are given in tables 3.4 to 3.5 From both periods of study, parameters like pH, conductivity, chlorides, sulphates, temperature, Oil and grease, calcium and potassium are within acceptable limits according to Malawi standards on surface water quality. The variables that were observed to exceed the limit are discussed in the subsequent paragraphs. Comprehensive data for levels of parameters in streams of Blantyre is provided in appendices 9 and 10.

Table 3.4: Physco-chemical characteristics of water streams of Blantyre city, Malawi –Dry Season (All parameters are in mg/l, except pH and as otherwise specified.)

STREAMS	Cl ⁻	DO	BOD	COD	T	pH	Alkalinity	SS	O & G	EC	PO ₄ ³⁻	NO ₃ ⁻	SO ₄ ²⁻
Limbe stream													
Mpingwe sports club	27.3	3.3	13.01	734.12	26	8.6	420	2.01	0.07	9	0.83	16.23	7.12
Highway bridge	30.2	4.1	22.12		28	8.3	450	25.30		11	4.26	139.94	21.19
Dalton bridge	32.7	3	36.0	1642.51	27	7.9	430	6.00	0.56	12	3.61	25.40	14.58
Naperi Stream													
Rainbow	49.7	3.1	16.50	402.0	26	7.9	380	37.09	0.02	6	ND	2.15	21.88
Moi road	30.2	3.5	27.06	623.65	26.5	8	340	24.53	0.78	5	0.77	138.87	36.94
Macro	32.7	4.2	30.09		27	7.8	320	38.02		4	ND	12.12	34.72
Kapeni	31.2	4.1	16.60		27	8	350	12.68		4	ND	67.97	33.125
Mudi stream													
M.D.I	33.4	5.2	230.04	316.01	26	8.1	400	19.07	0.57	8	ND	1.56	83.83
WICO	34.8	4.5	180		26	7.8	420	65.63		4	2.82	0.59	17.45
S.R.N	25.6	4	270.44	950.43	26	7.3	380	32.05	1.03	5.5	4.62	5.08	11.70
Clock Tower	36.9	4.8	240		26	7.1	540	25.67		7	6.92	7.23	13.30
Blantyre market	35.9	4.6	180.82		26	7.4	610	23.21		5	2.69	1.95	13.09
Victoria avenue	39.1	4.1	300.5		26	7.5	670	36.02		8	2.56	0.29	8.62
Nasolo stream													
BNC	83.4	4.2	96.0	778.0	26.5	8.4	430	18.00	0.07	17	5.0	111.25	15.54
S.R.N	53.37	1	122.0	691.56	26	6.5	520	42.11	2.46	20	8.61	8.37	18.98
Chirimba stream													
Behind Cori	22.7	3.8	42.2	821.0	27	7.5	590	13.00	0.164	9	5.77	243.07	8.47
Machinjiri road	25.3	3	30.0		27	7.2	420	39.78	1.38	20	10.26	6.64	103.61
Zalewa road	36.7	4	38.0	864.01	27	7.7	550	19.06		17	19.2	10.84	116.77

Table 3.5: Physco-chemical characteristics of water streams of Blantyre city, Malawi –Wet Season. (All parameters are in mg/l, except pH and as otherwise specified)

STREAMS	Cl ⁻	DO	BOD	COD	T ° C	EC mS	pH	MA	SS	O & G	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻
Limbe stream													
Mpingwe sports club	28.42	2.51	11.08	346.03	25.1	3	7.7	220	42.99	1.67	33.31	ND	16.23
Highway bridge	55.40	1.37	51.0		25	4.6	7.2	280	7.00		7.88	ND	23.04
Dalton bridge	51.81	1.2	54.03	410.06	24.7	4.6	7.2	210	3.02	5.30	32.95	ND	22.75
Naperi Stream													
Rainbow	33.76	1.42	16.5	1015.05	25.2	2.9	7.4	290	5.00	0.17	28.47	ND	5.36
Moi road	31.90	0.67	16.0	389.04	25.7	2.8	7	370	22.11	0.06	1.88	ND	7.97
Macro	34.83	2	4.51		25	3	7.5	280	27.00		13.51	ND	7.46
Kapeni	28.4	2.86	14.03		25	2.8	7.3	360	3.98		49.64	ND	6.01
Mudi stream													
M.D.I	26.66	7	41.9	324.98	24.3	3.1	7.6	240	16.05	0.73	16.91	4.0	10.00
WICO	35.50	2.13	39.0		25.2	4.1	7.4	300	40.01		2.6	1.14	11.23
S.R.N	32.70	1.04	36.0	346.04	24.5	3.6	7.1	280	6.00	2.29	2.75	1.71	5.80
Clock Tower	41.20	0	26.50		25	4.6	7.7	450	14.20		1.73	2.00	7.03
Blantyre market	41.91	1.36	11.0		24.5	4.2	7.8	390	38.00		0.15	2.57	6.09
Victoria avenue	37.60	0.3	8.52		24.5	4.8	7.6	400	26.01	0.11	0.87	3.43	7.10
Nasolo stream													
BNC	72.40	3.17	35.0	389.44	24	6.2	8	410	26.00	0.73	37.57	ND	28.99
S.R.N	53.61	1.04	28.01	310.00	24.5	3.6	7.7	500	8.01	0.67	8.09	ND	13.04
Chirimba stream													
Behind Cori	26.31	2.86	70.5	691.34	25.2	3.5	7.1	390	46.00	0.98	9.68	0.29	19.56
Machinjiri road	24.90	1.71	12.60		25.2	4	6.9	380	283.78	2.61	9.33	1.43	36.16
Zalewa road	44.72	3.29	18.51	790.21	25	5	8.1	380	40.00		37.57	5.43	37.10

KEY: ND stands for Not detected

3.2.1 Nutrients in the Blantyre city streams

Nitrates that pose a gross threat to the health of infants and pregnant mothers at levels higher than 10mg/l were observed to be high in all the streams except Mudi River in the dry season where the values in the streams affected went as high as 139.94 ± 0.50 mg/l for Limbe downstream, 138.87 ± 9.11 mg/l for Naperi downstream, 111.25 ± 14.39 mg/l for Nasolo upstream and 243.07 ± 6.73 mg/l for Chirimba upstream. The levels observed are much higher than the World Health Organisation limit (50mg/l) for the surface water primarily to be used as potable water. In the wet season, generally the levels of nitrates were found to be lower than the results in the dry season probably due to dilution effect although the levels were still higher than the 10mg/l limit set by Malawi standards. The highest levels observed in streams included Mudi upstream (16.91 ± 0.0), Nasolo upstream (37.57 ± 0.0), Naperi downstream (49.64 ± 8.89), Limbe upstream (33.31 ± 1.74) and Chirimba downstream (37.57 ± 0.0). The blocked sewerlines serving the industrial areas could have significantly contributed to the high nitrates levels observed.

As observed the mean levels of nitrates in the industrial effluents were 27.70mg/l and 12.69 in the dry and wet seasons respectively. The average levels in the industrial effluents are relatively lower than the mean concentrations in the streams. This fact coupled with the observation that most of the hot spots identified lie well before the industrial area, it therefore suggest that other sources like dumping of human wastes, surface runoffs from agricultural fields and diffuse sources from settlements might have equally contributed. It is a common practice in Blantyre city that people dump waste and cultivate maize along the river banks.

The levels phosphates in the dry season were well pronounced in all the streams except Naperi stream, which registered 0.77mg/l at one of its sampling point. The levels of phosphate in all the streams exceeded the 0.15mg/l Malawi standard. The extreme levels were observed in Mudi, Nasolo and Chirimba streams where the values ranged from 2.82 mg/l upstream to 6.92 mg/l downstream for Mudi whilst Nasolo stream values were found to lie between 5.0mg/l upstream and 8.61 downstream. Chirimba stream registered the highest levels of phosphate where the range was found to lie between 5.77 mg/l upstream to 19.2mg/l downstream. In the wet season, phosphates levels were only observed in Mudi and Chirimba streams. The levels in Mudi ranged from 1.14 mg/l to 4.0 mg/l, both points being upstream whilst levels in Chirimba stream ranged from 0.29mg/l upstream to 5.43mg/l downstream. Significant increases were observed in both

streams after passing through industrial areas. Other studies have made similar observation that phosphates levels tend to significantly increase downstream (Fakayode, 2005; Phiri et al, 2005). The phosphates levels in the streams of Blantyre city are slightly higher than those reported for Alaro River in Nigeria by Fakayode, 2005 which registered downstream average phosphate level of 4.62 mg/l due to industrial effluent discharges.

The streams in Blantyre city might have been infested with phosphate emanating from industrial effluents due to blocked sewers in the case of Mudi and Nasolo which happen to be the streams that sandwich the heavy industrial area of Makata industrial area. In addition, Mudi stream runs between ginnery corner industrial area and Makata where some industries like chemicals, brewery, abattoir A, and printing A exhibited high levels of phosphates. On the other hand, the observed exacerbated levels in Chirimba stream can be attributed to the discharge of effluent from an edible oil refinery A situated along its banks. The sewerlines in Chirimba industrial area is non functional as such effluent from industries is discharged direct into the stream. In all cases of streams being highly polluted with phosphates, the levels could also be to farming activities taking place along the streams whereby farmers apply phosphates fertilizers in their fields. Other studies have pointed out that values higher than 0.34 to 0.70 mg/l for both phosphate and nitrate would cause eutrophication related problems in tropical zones (Fatoki, 2000; Rast and Thornton, 1996). This therefore explains why most of the streams in Blantyre city algal infestations are well pronounced. Holdsworth (1991) reported that cyanotoxins from blue green algae caused death of farm livestock. It therefore suggests that if the water quality of streams persists, the risks of death are imminent for livestock that is fed on this water because of toxic substance cyanotoxins.

3.2.2 BOD and COD in Blantyre city streams

From tables 3.4 and 3.5, the values of COD in all the streams in both seasons exceeded the limit of 60mg/l set by Malawi bureau of standards on surface water. The extreme values in the dry season were noted at Limbe downstream (1642.51 ± 26.7 mg/l), Mudi downstream (950.43 ± 10.3 mg/l) and the whole course of Chirimba, which registered 821.0 ± 2.1 mg/l upstream and 864.01 ± 7.3 mg/l downstream. In the wet season most of the values were relatively lower than the dry season results. In this period the extreme values were observed at Naperi upstream which reached 1015.05 ± 50.45 mg/l. On the other hand, the whole course of Chirimba stream exhibited high levels ranging from 691.34 ± 12.24 mg/l upstream to 790.21 ± 10.28 mg/l downstream.

The levels of BOD in all the streams in the dry season far exceeded MBS limit 20mg/l except at Limbe upstream point (13.01 ± 0.90 mg/l) and Naperi stream where farthest upstream and downstream points registered 16.50 ± 2.10 mg/l and 16.60 ± 2.0 mg/l respectively. Mudi stream was observed to be the worst where the BOD levels ranged from 180.0 ± 3.1 mg/l to 300.50 ± 10.4 mg/l. In wet season the levels of BOD were relatively lower than the dry season results although 50 % of the sampling points values were above the limit of 20mg/l. The extreme values were observed in Limbe downstream points where levels were 51.0 ± 12.73 mg/l and 54.03 ± 2.83 mg/l, and Chirimba stream upstream reached 70.5 ± 0.71 mg/l. The least polluted was Naperi where all the BOD values were found to be below the MBS limit.

The high values of COD and BOD observed in the streams could arise from manhole overflows, which were quite common during the study period. The sewerlines conduits both domestic and industrial effluents of high BOD and COD levels which, if obstructed ends up in the streams. As shown in the previous sections, the average levels of BOD and COD in industrial effluents in the dry season were 584.17mg/l and 5283.05 mg/l respectively whilst in the wet season the mean values were 4504.76mg/l for COD and 454.53 mg/l for BOD. These levels are quite so high that if the effluents are discharged into the stream either through blockages or sewer pipe burst, the impact on the receiving is expected to be great. This reason compounded with the fact that some industries dump solid waste along the banks, the levels of aggregate organic pollution were high in all the streams. Although the levels were lower in the wet season due to dilution effect, the levels observed in these streams are a big threat to aquatic life and aesthetic value of the water. The effect of these high COD and BOD concentrations in the streams of Blantyre City could be severe because they create oxygen stress as a result of bio decomposition of the organic waste thereby affecting aquatic biota.

3.2.3 Levels of metals in the streams of Blantyre City

Although possible sources of metals were identified in the industrial effluents, the prevalence of the same metals was scanty in most of the streams that host the industries.

3.2.3.1 Copper

In the dry season, traces of copper were observed at Limbe upstream (0.048 ± 0.0 mg/l) and downstream (0.296 ± 0.01 mg/l), Naperi downstream (0.024 ± 0.01) and Chirimba downstream (0.208 ± 0.0 mg/l) whilst in the wet season copper levels were only traced at Limbe upstream

($0.068 \pm \text{mg/l}$). The copper levels in all the streams were less than 1.00 mg/l limit set by Malawi Bureau of Standards. Copper levels in these streams could be attributed to spillages of effluent from textile industries and copper metals that might have been dumped into the streams.

3.2.3.2 Cadmium

Cadmium was only detected in the dry season at all the sampling points in Mudi stream. The levels are given in figure 3.13

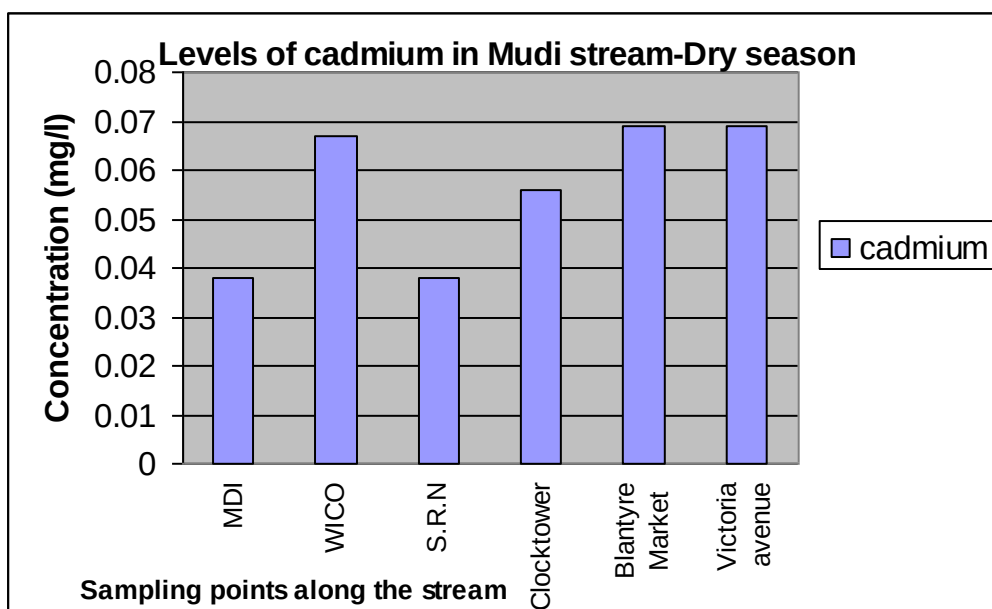


Figure 3.13: Levels of cadmium in Mudi River

The levels were observed well even before industrial area, however the levels increased to $0.067 \pm 0.003 \text{mg/l}$ after passing through abattoir 'A' whose effluent registered $0.060 \pm 0.005 \text{mg/l Cd}$. The levels decreased to lower levels at the S.R.N sampling point, but thereafter the levels increased to $0.069 \pm 0.007 \text{mg/l}$ at the farthest downstream point (Victoria Avenue). The levels observed in Mudi stream exceed the safe limit of 0.005 mg/l set by both MBS and WHO. Apart from industrial effluents contributing to the cadmium levels in the stream, the levels are likely to be exacerbated by phosphate fertilizer, which is commonly used in the farming field along the banks since fertilizer is a natural sink of cadmium.

Recent data indicate that adverse health effects of cadmium exposure may occur at lower exposure levels than previously anticipated, primarily in the form of kidney damage but possibly also bone effects and fractures (Lars Järup, 2003). If the occurrences of such levels persist in

Mudi stream, then consumers of water from this stream are at a high risk of suffering adverse health disorders because cadmium is extremely toxic.

3.2.3.3 Nickel

Nickel was only observed in Mudi stream at two sampling points in the dry season. At both S.R.N and Blantyre market the values were 0.222 ± 0.0 mg/l. The nickel levels observed exceed the MBS limit (0.1mg/l) and WHO limit (0.02mg/l) for nickel. The nickel levels however were not observed at the farthest downstream suggesting that the dilution had taken its effect on the pollutant. The most likely source of the nickel might have been effluent from food processing industries like abattoir where the levels were observed in both season. Foodstuffs naturally contain small amounts of nickel (Lenntech, 2006). Nickel in small quantities is essential but in excess amounts it can lead to higher chances of development of lung cancer, nose cancer, larynx cancer and prostate cancer.

3.2.3.4 Iron

Iron was observed at all the sampling points in all the streams in the wet season ranging from 0.84 ± 0.07 mg/l in Nasolo stream to 2.45 ± 0.20 mg/l in the Chirimba middle stream point whilst in the dry season the levels were sparse ranging from non traceable levels in the whole course of Naperi and Chirimba streams to 1.58 ± 0.03 mg/l in Mudi downstream (figure 3.14). Levels of iron were predominant in all the streams in the wet season probably due to rainwater surface runoffs which carried iron salts from other sources other than industries as evidenced by high levels of the iron levels at upstream points like Mudi MDI (2.06 ± 0.67 mg/l), Limbe Mpingwe (1.37 ± 0.02 mg/l), Nasolo BNC (0.84 ± 0.28 mg/l). Most of the observed levels of iron in the streams exceed the Malawi standards limit of 0.20mg/l for surface water. High levels of iron oxides may result in development of a benign pneumoconiosis, called siderosis (lenntech, 2006).

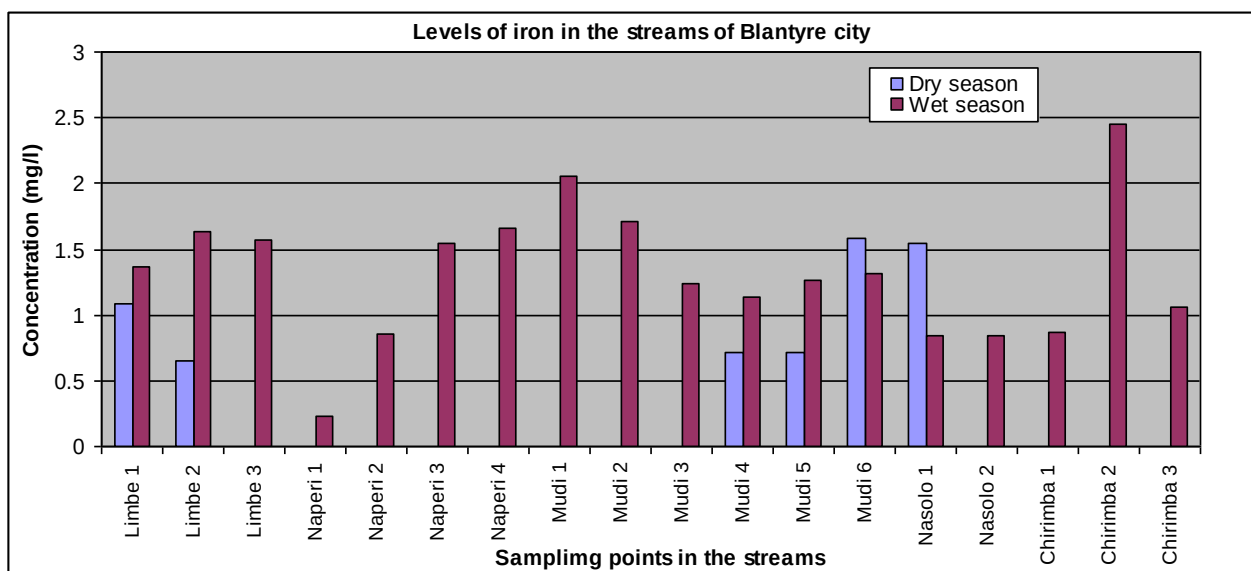


Figure 3.14: Levels of Iron in the streams of Blantyre city

3.2.3.5 Manganese

The levels of Manganese were more pronounced in the dry season than in wet season in all the streams except in Mudi stream stretch where the levels of manganese were traced at all the sampling points (figure 3.15).

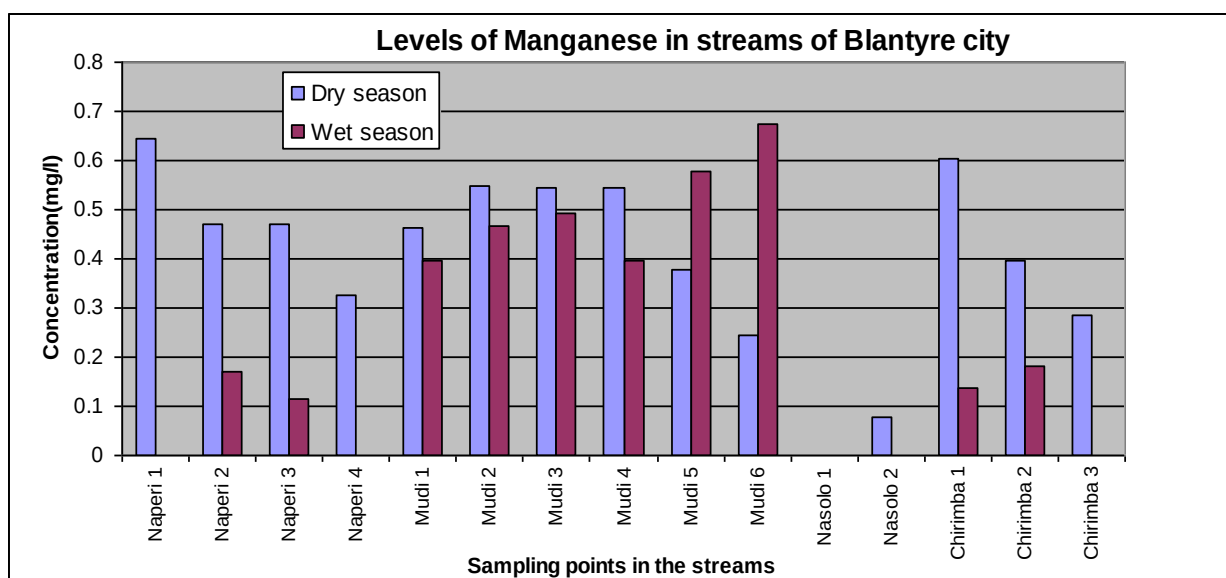


Figure 3.15: Levels of Manganese in the streams of Blantyre

The levels of manganese in the dry season were found to range between 0.079 mg/l in Nasolo downstream to 0.646mg/l in Naperi upstream whilst in the wet season the concentrations of

manganese ranged from 0.114mg/l in Naperi downstream to 0.675mg/l at the farthest point in Mudi downstream (figure 3.15). In both period of study, levels of manganese were not detected in Limbe stream. The levels of manganese at all the sampling points exceed the Malawi standard limit of 0.1mg/l except Nasolo downstream.

The observed trend on levels of manganese in the all streams suggests that there were other sources apart from industrial effluents that contributed to the levels because in streams like Naperi, Chirimba, high levels in the dry season were noticed well before the area of industrial activities whilst in Mudi stream the levels significantly increased at the farthest points downstream after the industrial area. Sewer overflows, which usually carry combined effluent and seepage from agricultural fields along the streams, are the likely sources of the observed high manganese levels.

3.2.3.6 Zinc

The levels of zinc in the streams were found to range from 0.07 ± 0.02 mg/l in Mudi downstream (Victoria Avenue) to 1.21 ± 0.01 mg/l Chirimba downstream (Machinjiri road). Apart from the two sampling points in Limbe stream and Chirimba stream, the metal was prevalent in Mudi stream whilst no levels were traced in Nasolo and Naperi streams (table 3.6). However at all the sampling points, the levels were below the maximum limit of 5mg/l and 3 mg/l set by Malawian standards and WHO guidelines.

Table 3.6: Levels of Zinc in streams of Blantyre City

Sampling point	Dry season Zinc in mg/l	Wet season Zinc in mg/l
Limbe stream –Highway	1.02 ± 0.38	ND
Chirimba- Machinjiri road	1.21 ± 0.01	ND
Mudi –MD1	ND	0.398 ± 0.0
Mudi –WICO	0.11 ± 0.03	0.008 ± 0.0
Mudi- SRN	0.082 ± 0.01	0.04 ± 0.01
Mudi -Clock tower	0.033 ± 0.006	ND
Mudi- Blantyre market	0.11 ± 0.05	ND
Mudi Victoria avenue	0.07 ± 0.02	ND

Key: ND stands for Not Detected

The level of zinc observed at Chirimba -Machinjiri road, which is an immediate downstream point after industrial area could have possibly emanated effluent from an edible oil refinery 'A' which registered 2.45 ± 0.06 mg/l and the effluent is usually discharged direct into the Chirimba stream. The traces of zinc in Limbe stream could be attributed to seepage and washings of scrap motor vehicles and motor oils that contain zinc constituents to prevent microbial growth from a garage allocated along the banks of Limbe stream. It is also possible that zinc levels observed were due to the fact that zinc finds wide application in fertilizers (zinc sulphate), white pigment in watercolours or paint and without ruling out its natural occurrence in the environment contributing substantially to the levels. Although zinc is a trace element that is essential for human health, too much zinc can still cause eminent health problems, such as stomach cramps, skin irritations, vomiting, nausea and anaemia. Very high levels of zinc can damage the pancreas and disturb the protein metabolism, and cause arteriosclerosis (lenntech 2006).

3.3 TREATMENT AND DIPOSAL OF WASTEWATER IN BLANTYRE CITY

Disposal of industrial wastewater has always been a major environmental issue. Pollutants in industrial wastewater are almost invariably so toxic that wastewater has to be treated before its reuse or disposal in water bodies (Tayim et al, 2005). Unlike in developed countries where industrial productions are usually done in an environmentally friendly manner through the use of modern and best available technologies or processes, many industries in developing countries still use either outdated or best practicable technology due to economic constraints (Fakayode, 2005). It was therefore imperative to study the mode of disposal of industrial effluents and efficiency of treatment plant used in averting the pollution load.

3.3.1 Industrial effluent disposal and pretreatment efficiencies

The study revealed that 50 % of industries pretreat their effluents. The effluent is usually disposed into the city sewer lines except on effluent from petroleum refineries and motor oil ‘B’ which discharge direct into the water bodies. The companies that discharge direct into the streams have the consent of local authority because their effluent is considered non-toxic based on BOD parameter (BCA, 2005). The effluent from the rest of the companies combined with domestic effluent is channelled to the main treatment plants through conduits that are located along the stream banks in following the natural slope and these sewer lines are a threat to water quality because of overflows due to frequent blockages and poor maintenance of the sewer structure which more often results into the effluents being discharged into the stream before it is treated by the local authority major wastewater treatment plants. The pretreatment plants commonly used in industries are given in table 3.7.

Table 3.7: Pretreatment plants in industries of Blantyre City

Type of pre-treatment	Industries using the system
Oil interceptors	Confectionery, Paints, Matches, Petroleum storage.
Oxidation ditch	Dairy
Oxidation pond	Abattoir B
Sedimentation tanks	Textile B, Abattoir A
Combination of sedimentation tank and oxidation ditch	Textile A
Edible oil effluent treatment plant	Edible oil refinery B

Barnes (1978) stated that the overall design of a plant often assumes that toxic materials are controlled to some acceptable level, and that hydraulic and pollution loads do not show erratic variation. It is from this background that this study determined the efficiency of pretreatment plants used by industries in reducing pollution load at source (tables 3.5 to 3.6). The formula used

to calculate removal % efficiency was as follows: $Removal(\%) = \frac{C_1 - C_2 \times 100}{C_1}$

Where C_1 and C_2 are variable concentrations before and after treatment respectively.

Table 3.8: Wastewater pretreatment removal % efficiencies

SOURCE	Cl ⁻	BOD	COD	Alkalinity	SS	O & G	EC	PO ₄ ³⁻	NO ₃ ⁻	SO ₄ ²⁻
DRY SEASON										
Abattoir A	7.29	17.37	-14.29	-50.37	78.62	-54.43	-4.0	9.99	61.30	-23.30
Abattoir B	-40.11	10.46	9.53	-103	56.85	23.53	-63.64	-408.06	-155.92	-104.71
Confectionery	2.79	44.28	76.29	40.91	98.45	81.89	-1100	11.16	88.86	0
Edible cooking oil B	11.70	69.09	8.74	4.25	16.37	93.48	-210.53	-11.66	16.01	11.81
Dairy A	-21.95	43.79	41.32	-3.54	-104.35	-597.37	-183	12.48	-114.33	27.51
Matches	2.25	63.69	-27.29	4.17	5.94	-	-96.6	-1198.7	-240.79	-124.79
Paint A	-10.0	19.39	-55.18	-135.05	18.26	76.77	-100	-72.47	-166.96	-6.43
Paint C	5.47	45.56	5.40	-27.91	67.60	78.35	-16.7	75.56	-36.79	64.96
Petroleum A	60.73	0.33	7.38	65.5	83.28	77.53	14.3	50.0	-190.73	-12.71
Petroleum B	45.88	40.48	-15.13	-25.0	88.26	55.49	0	-25.23	44.08	-24.47
Textile A	-18.42	15.53	13.78	-126.47	61.25	-	-63.2	100	-3.80	94.84
Textile B	7.48	12.71	26.22	100	39.62	-	-550	25	-3383.9	-1.03
WET SEASON										
Abattoir A	-33.66	37.36	35.47	-4.4	-54.72	86.66	59.375	62.27	25.24	48.65
Abattoir B	-	-	-	-	-	-	-	-	-	-
Confectionery	-37.92	6.66	45.31	5.26	-10	47.40	88.26	67.40	-29.62	-686.21
Edible cooking Oil B	-34.53	60.16	-130.98	-42	-268.97	37.83	89.39	-79.82	-270.37	-3849.87
Dairy A	62.17		-34.61	-39		-42.64	87.54	26.70	-171.5	-94.70
Matches	-36.67	28.44	-37.92	1.32	-12.20	-141.07	-		-169.93	-211.65
Paint A	10.05	25	12.90	7.92	39.02	61.27	85.23	-267.55	5.34	0
Paint C	8.11	46.67	38.72	-2.9	3.33	-0.03	-126.74	-846.92	-801.75	65.93
Petroleum A	-5	12	12.53	1.45	18.18	21.54	25.93	32.35	0	65.04
Petroleum B	26.04	46.40	48.51	2.7	10	39.00	52.55	2.38	0	21.25
Textile A	7.40	15.11	40.74	-2.6	-14.29	23	-	67.25	57.25	100
Textile B	32.28	44.92	-39.15	2.82	8.33	9.03	-	-53.96	-57	-127.90

The results indicated that efficiencies of industrial pretreatment facilities differed from one system to another. The differences in performance were due to treatment technology employed and the amount of waste entering the plant. In the dry period, the oil interceptor at a confectionery industry showed the best performance where it significantly reduced concentrations for all variables except sulphates and electrical conductivity. The removal efficiency ranged from 2.79% on chlorides to 98.45% of suspended solids. In the wet season, generally the pretreatment plants removal efficiencies were relatively lower than in the dry season. However, oil interceptors from paint 'A' and petroleum 'B' industries were able to reduce the pollutants considerably. The removal efficiencies for oil interceptor at paint 'A' ranged from 5.34% nitrates to 61.27 % oil and grease whilst for petroleum plant the performance ranged from removing 2.7% of alkalinity to 52.55% electrical conductivity.

Evaluation of the degree of removal of pollutant revealed that BOD was almost removed by all treatment plants (table 3.8). The overall order of efficiency of treatment plants in removing pollutants was as follows; BOD >SS, O&G> COD, >Cl⁻ > PO₄³⁻>Alkalinity> SO₄²⁻>EC >NO₃⁻. As shown in table 3.9, removal efficiencies of heavy metals and valuable cations like potassium and calcium greatly varied from each treatment plant type depending on the presence of the variable under study. It is shown that in the dry season oil interceptor at confectionery industry performed the best where the efficiency percentage ranged from 54.58% removal of potassium to 100% removal of nickel and manganese. In the wet season, not many heavy metals were observed, however sedimentation tanks at abattoir A showed a remarkable ability to remove the metals within the system where the efficiency ranged from 7.24% for manganese to 100% removal for copper. Oil interceptors at the paint plants were able to remove lead by 26.70% to 32.60% implying that there could be more lead levels discharged into the public sewerlines if it were not for the existence of these pretreatment plants.

It was generally observed that some of the pollutants like phosphates, nitrates, sulphates and other metals survived through the process of treatment and the levels increased hence numerous negative efficiency removal percentages (table 3.8). Studies by Omoregbe (2005) and Wilkison (2000) observed similar trend that some levels of pollutants were higher in influent than effluent in wastewater treatment plants. This could probably be attributed to the pollutants, which are synergistically produced from biodegradability of the wastes as it is being retained within the treatment system. This observation could be also be due to the complexity and variation of industry effluent quality, which can differ hourly, daily and seasonally because industrial effluent

is usually intermittent other than ‘batch’ as such depending on the size of the treatment plant which in turn determines retention time, the homogeneity of effluent within the system is hardly achieved.

Table 3.9: Wastewater Pretreatment removal efficiencies %, for heavy metals and cations.
(All parameters are in mg/l)

SAMPLING POINT	Cu	Ni	Cd	Cr	Pb	Fe	Zn	Mn	K	Ca
DRY SEASON										
Abattoir A	ND	33.33	7.69	ND	ND	64.56	20	-118.97	0.75	-15.76
Abattoir B	100	ND	ND	ND	ND	-100	-84.29	100	0	54.69
Confectionery	62.5	100	80	ND	ND	59.63	91.68	100	54.58	85.17
Edible Cooking Oil B	-44.91	ND	-7.69	ND	ND	100	54.44	-13.33	0	-9.74
Dairy A	-41.67	ND	ND	ND	ND	100	100	48.45	-0.20	-12.76
Matches	12.90	100	100	-133.52	ND	-100	-5.45	61.72	-2.04	-4.98
Paint A	-1100	ND	80	ND	32.60	ND	-6.67	31.73	-31.87	37.16
Paint C	-309.00	ND	ND	ND	26.70	ND	36.36	-42.32	-3.26	19.07
Petroleum A	ND	ND	ND	ND	ND	-53.57	ND	ND	2.70	-4.90
Petroleum B	ND	ND	ND	ND	ND	-21.24	49.12	ND	13.72	16.85
Textile A	39.30	100	ND	ND	ND	45.33	100	ND	-111.77	-69.71
Textile B	-44.872	ND	31.71	ND	ND	ND	-120	-0.69	-0.20	-24.71
WET SEASON										
Abattoir A	100	15.42	ND	ND	ND	18.04	79.07	7.24	11.07	-73.11
Abattoir B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Confectionery	ND	ND	ND	ND	ND	-113.08	100	ND	-3.10	-16.51
Edible cooking Oil	ND	ND	ND	ND	ND	-180.70	23.08	-1363.64	-111.37	-4.20
Dairy A	ND	ND	ND	ND	ND	-557.00	ND	ND	-18.66	78.14
Matches	ND	ND	ND	-54.77	ND	-163.64	-50.29	ND	ND	30.96
Paint A	ND	ND	ND	ND	ND	80.71	ND	ND	2.26	-91.46
Paint C	-61.76	ND	ND	ND	ND	19.46	18.25	13.67	-0.14	-1.08
Petroleum Storage A	ND	ND	ND	ND	ND	48.29	ND	ND	15.31	15.38
Petroleum Storage B	ND	ND	ND	ND	ND	-19.92	ND	ND	-20.00	5.48
Textile A	-60.12	ND	ND	ND	ND	-232.95	ND	ND	-4.09	-16.10
Textile B	-34.31	30.00	ND	ND	ND	-724.59	-38.46	96.55	-1.09	1.41

KEY: ND means the variable was not detected at the outflow point.

From the study of efficiency of pretreatment plants used by industries, it could therefore be inferred that pretreatment plants being used by industries have the ability to reduce the levels of pollutants before they are discharged into either the stream or the sewerline although they have equal chances of failing to reduce some pollutant variable as shown by negative efficiency percentages. The pollutants are removed through sludge that settles down to the bottom of the treatment plants and scum that is usually scooped out of the system hence the positive efficiency whilst negative removal efficiency could arise from the pollutants being synergistically formed within the system. In other cases the negative efficiency could be due to variation of products, which determines different effluent characteristics. A good example could be at one of the dairy plants where milky wastewater was observed indicating that production of milk preceded the production of juice whose waste wastewater being collected at the time of sampling.

3.3.2 Efficiency of Blantyre City Assembly wastewater treatment plants.

Industrial effluents are discharged into combined sewerline system that ultimately empties into the major wastewater treatment plants. It was therefore deemed necessary to study the levels of pollutants reaching these treatment plants and at the same time determine the efficiency of the treatment plants in reducing the pollution load so as to determine the threat pollutants carried through industrial effluents reaching the wastewater treatment plants pose to the streams receiving final effluents. Tables 3.8 to 3.9 display results on levels of pollutants in both the influent and effluent and corresponding efficiencies of wastewater treatment plants.

3.3.2.1 Characteristic of effluent at Blantyre City Assembly Wastewater Treatment Plant

From tables 3.10 and 3.11, it is clear that variables such as chlorides, BOD, COD, oil and grease, suspended solids, phosphates, nitrates were observed to be prevalent and at other sampling points the concentrations were higher than what was observed in industrial effluents. The levels of metals were conspicuously sparse at all treatment plants except for calcium and potassium which were noted at all sampling points. Manganese on the other hand, was observed at all treatment plants except at Soche wastewater treatment plant in both period of study. This could be due to the dilution effect resulting from proportion of industrial wastewater (30%) to domestic wastewater (70%) treated at the treatment plant. Some of the metals of interest like lead, nickel, chromium were not detected at any of the sampling point whilst cadmium was detected in small amounts at Limbe and Soche wastewater treatment plants in the dry season only.

Sajidu et al (2006) reported that wastewater in the Blantyre City Assembly wastewater treatment plants exhibited traceable levels of metals (Pb, Mn, Cd, Ni, Zn, Fe, Cr, Cu). However in this study metals of interest like Pb, Ni and Cr were not detected in wastewater treatment plants probably due to the fact the sewerlines which determines the volume of wastewater reaching the treatment plants were experiencing serious overflows due to blockages as such insignificant levels of some pollutants could not impact the quality of wastewater in the wastewater treatment systems.

3.2.2.2 Efficiency of wastewater treatment plants

The results on the efficiency of main wastewater treatment plants in Blantyre City are provided in tables 3.10 to 3.11

Table 3.10: Performance of Blantyre City Assembly wastewater treatment plants

TREATMENT PLANTS	Cl ⁻	DO	BOD	COD	T	pH	Alkalinity	SS	O & G	EC	PO ₄ ³⁻	NO ₃ ⁻	SO ₄ ²⁻
DRY SEASON													
Blantyre Sewage Plant													
Raw	34.8	0	440.06	1642.3	27	6.6	400	210.02	0.073	7	7.41	44.80	46.45
Final	33.4	1.2	58.0	691.01	27	7.3	610	232.08	0.018	9	10.74	152.92	44.11
Concentration removal %	4.02	+	86.82	57.92	3.23	-32	-52.5	-10.50	75.34	-29	-44.94	-241.34	5.04
Limbe Sewage plant													
Raw	53.3	0	740.0	1296	31	7.4	410	220.0	1.59	10	21.54	5.27	34.86
Final	76.0	4.3	50.5	777.05	30	9.8	440	16.04	0.039	1	4.44	17.58	30.833
Concentration removal %	-42.59	+	93.18	40.04	3.23	-32	-7.32	92.71	97.55	90	79.39	-233.59	11.55
Soche sewage plant													
Raw	44.0	0	490.0	883.30	26	7.1	560	157.0	1.84	20	10.0	12.45	20.93
Final	46.2	0	24.82	353	26	7.3	450	101.65	0.34	16	12.5	9.42	22.66
Concentration removal %	-5.0	+	94.93	60.04	0	-28	19.64	35.25	81.52	20	-25.0	24.34	-8.27
WET SEASON													
Blantyre sewage plant													
Raw	36.9	1.38	510	691.11	25.8	6.7	400	29.01	8.73	4.5	0.57	84.47	8.26
Final	36.20	2.62	450	503.01	26.6	7.0	370	25.91	3.61	4.1	0	32.37	7.75
Concentration removal %	1.90	+	11.76	27.22	-3.10	-4.5	7.5	10.69	58.65	8.89	100	61.68	6.17
Limbe sewage plant													
Raw	48.29	1.94	810.5	821.32	26.1	7.1	280	268.45	3.85	3.4	2.29	61.68	8.48
Final	34.10	4.69	63.0	778.56	27.1	9.1	240	214.0	0.23	3.9	0	30.58	0
Concentration removal %	29.38	+	92.23	5.21	-3.83	-28	14.29	20.28	94.03	-15.0	100	50.42	69.22
Soche sewage plant													
Raw	40.51	0	760.0	907.0	26	7.0	360	40.0	7.23	3.9	1.43	33.09	14.49
Final	39.10	1.18	33.90	734.90	25.4	7.3	180	8.02	2.10	3.3	1.71	218.92	17.25
Concentration removal %	3.48	+	95.54	18.97	2.31	-4.3	50	79.95	70.95	15.4	-19.58	-561.59	-19.05

Key: + for DO means the level increased

**Table 3.11: Levels of metals and cations at Major treatment plant of Blantyre City
Assembly**

	Cu mg/l	Ni mg/l	Cd mg/l	Cr mg/l	Pb mg/l	Fe mg/l	Zn mg/l	Mn mg/l	K mg/l	Ca mg/l
TREATMENT PLANTS										
DRY SEASON										
Blantyre Sewage Plant										
Raw	0.040	ND	ND	ND	ND	ND	0.035	0.378	19.95	21.76
Final	0	ND	ND	ND	ND	ND	0.044	0.399	19.96	21.65
Concentration removal %	100						-25.71	-5.55	-0.05	0.51
Limbe Sewage plant										
Raw	0.104	ND	ND	ND	ND	ND	0.45	0.479	19.94	17.71
Final	0.096	ND	0.014	ND	ND	1.00	0.017	0.383	19.93	19.12
Concentration removal %	7.69		-			-	96.22	20.04	0.05	-7.96
Soche sewage plant										
Raw	ND	ND	ND	ND	ND	0.79	0.15	ND	19.99	12.47
Final	ND	ND	0.002	ND	ND	1.42	ND	ND	19.99	11.12
Concentration removal %			-			-79.75	100		0	10.83
WET SEASON										
Blantyre Sewage plant										
Raw	ND	ND	ND	ND	ND	0.49	0.014	0.073	11.51	19.82
Final	ND	ND	ND	ND	ND	0.63	0	0.116	9.73	18.65
Concentration removal %						-28.57	100	-58.90	15.46	5.90
Limbe sewage plant										
Raw	ND	ND	ND	ND	ND	0.10	ND	0.037	11.13	17.82
Final	ND	ND	ND	ND	ND	1.08	ND	0	11.04	14.53
Concentration removal %						-980		100	0.81	18.46
Soche sewage plant										
Raw	ND	ND	ND	ND	ND	0.297	ND	ND	10.75	11.65
Final	ND	ND	ND	ND	ND	0.072	ND	ND	11.35	9.82
Concentration removal %						75.56			-5.58	15.71

KEY: ND means not detected

The data revealed that wastewater treatment plants were more efficient in reducing COD, BOD, oil and grease, suspended solids (table 3.10 and figure 3.16).

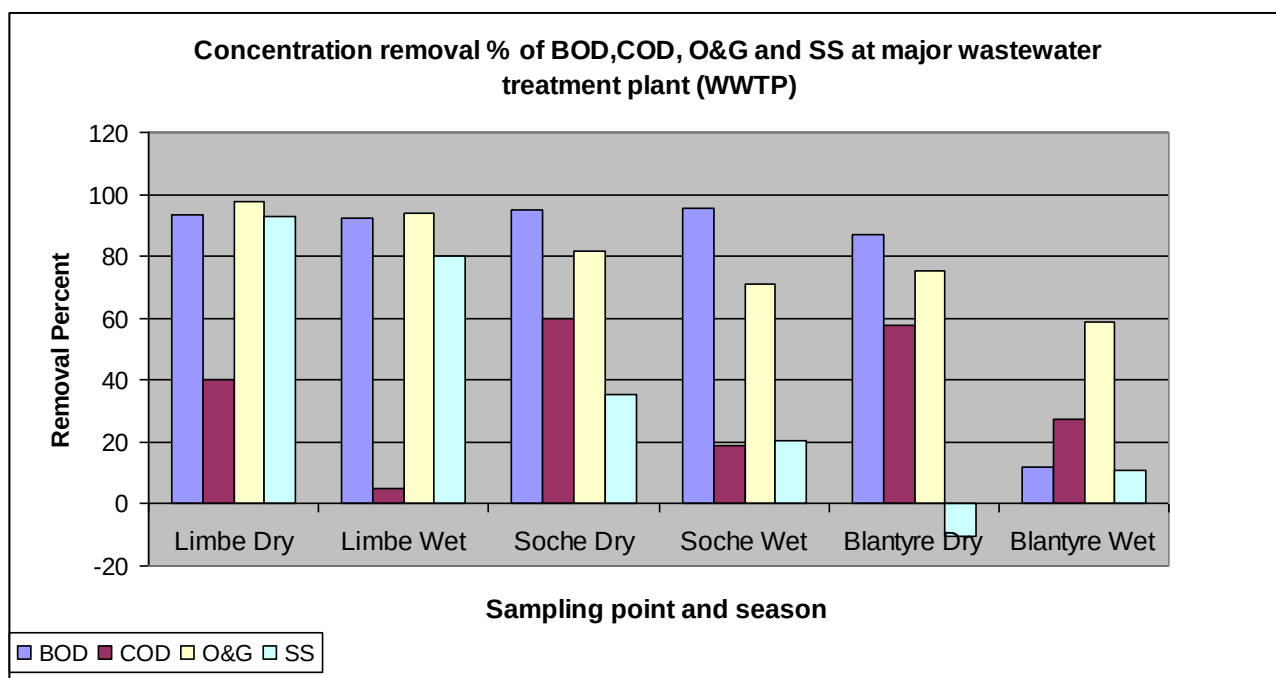


Figure 3.16: Removal efficiencies of BCA WWTP on BOD, COD, Oil and Suspended solids

All the wastewater treatment plants under study were observed to increase the levels of dissolved oxygen and pH in the final effluent for both seasons whilst removal efficiency percent of biochemical oxygen demand in the dry season ranged from 86.82% for Blantyre WWTP to 94.93% at Soche WWTP. The efficiency of Blantyre WWTP reached as low as 11.76% in the wet season probably due to breakdown of some components of the system which were undergoing through rehabilitation during the time of study. On the other hand the efficiency percent removals of BOD for Limbe WWTP and Soche WWTP in the same period were as high as 92.23% and 95.54% respectively.

The levels of COD were much lower in the dry season than in wet season in all the treatment plants. During the dry season the efficiencies ranged from 40.04 % in Limbe WWTP to 60.04% at Soche WWTP whilst in the wet season the efficiency ranged from 5.21% at Limbe WWTP to 27.22% at Blantyre WWTP. The observed low efficiency observed on COD could be due to the plants being overloaded with volumes of water because of the rainwater which in return reduces retention time of the wastewater. However in all cases the difference in concentrations between the influent and effluent were significant ($p < 0.05$, Independent t test).

The removal efficiency of suspended solids varied between each plant and seasons. Blantyre WWTP failed to reduce the pollution load (-10.50 %) in the dry season whilst Limbe WWTP was at its best removing 92.71% of the suspended solids. In the wet season the order of efficiency showed Soche WWTP removing 79.95% of the suspended solids whilst Limbe WWTP ranked second removing 20.28 % and Blantyre WWTP was the least reducing the suspended solids by 10.69 % only (figure 3.16). It was generally observed that all treatment plants were able to reduce substantially the levels of oil and grease (O&G). The efficiencies ranged from 75.34% at Blantyre WWTP to 95.55% at Limbe WWTP in the dry season whilst in the wet season the efficiency were found to range from 58.65% for Blantyre WWTP to 94.03% at Limbe WWTP.

The other variables like phosphate, nitrates and sulphate were found to survive through the treatment systems and in other cases the levels in the effluent were higher than influent levels. Nevertheless, in the dry season phosphates levels were removed by 79.39 % whilst nitrates were removed by 24.34% at Limbe WWTP (table 3.8). In the wet season phosphate levels were removed by 100% by both Blantyre and Limbe wastewater treatment plants .The same observation was made on nitrates which were removed by 61.68% and 50.42% at Blantyre WWTP and Limbe WWTP respectively. In addition Limbe WWTP was the only plant that reduced the sulphates levels substantially by 69.22% (Table 3.10).

The study carried out by Nantel, 1995 in Quebec on effectiveness of municipal wastewater treatment plants revealed average removal efficiencies of 81.9% for suspended solids, BOD (51.9%), phosphorous (73.9%) and oil and grease on 58.3%. The trend in removal efficiencies of variables in the Quebec study agrees with removal efficiencies of some parameters like phosphate whilst in other variable like BOD the municipal WWTP in this study are more effective.

The effectiveness of treatment plants in reducing metals showed that most of the identified metals were insignificantly reduced and in other cases the metals survived through the system. However positive reductions were observed in removal of some variables. Copper was removed in the dry season at Blantyre WWTP (100%) and Limbe WWTP (7.69%). Iron was only significantly reduced at Soche WWTP (75.56%) in the wet season. Zinc on the other hand was observed to be reduced by 100% at both Limbe and Soche wastewater plants in the dry season. In the wet season zinc was only observed at Blantyre WWTP where it was removed completely

(table 3.8). Manganese was not observed at Soche WWTP in both season, a situation contrary to what was observed at Limbe WWTP where it was reduced by 20.04% and 100% in both the dry and wet seasons respectively. The efficiencies of the treatment plants in reducing calcium and potassium were observed to lie below 19% in the whole period of study. The heavy metals and cations might have been removed from the wastewater through precipitation of their carbonates and oxides adsorption mechanism (Tayim et al, 2005) and eventually removed as sediments which either settles on the bottom of the treatment plants or scooped out as scum.

The results on removal efficiencies of the wastewater treatment plant compares favourably with the Quebec scenario (Nantel, 1995) where the removal percentages for iron, copper and zinc were -39.0%, 50% and 49.1% respectively whereas in this study the removal percentages were 75.56% for iron, 100% for zinc and copper registered 100% removal % at Blantyre WWTP and 7.69% at Limbe WWTP.

CHAPTER 4: CONCLUSION AND RECOMMENDATIONS

4.1 CONCLUSION

Characterizing and quantifying watershed pollutant sources can provide information on the relative magnitude and influence of each source and its impact on stream water quality. The study has shown that wastewater generated by the industries in Blantyre city is heavily polluted; the wastewater has very high quantity of suspended solids, high quantity of organic and inorganic materials (as indicated by high values of BOD and COD). Nearly 50% of these industries discharge effluents with COD and BOD levels exceeding the limit as regulated Blantyre City Assembly.

While temperature is generally not a problem with most of the industries, but the battery industry releases effluent between 70 °C and 100 °C exceeding the public sewer discharge limit of 40 °C. The acidity of most of the effluents is within the Blantyre City Assembly regulation of neutral range except bottling, brewery, dairies, paint, vegetable cooking oil and confectionery industries. The major source of chlorides is the battery industry while the cooking oil refinery A is responsible for high levels of sulphates. Companies such as textile, matchstick, Abattoirs showed a high potential of discharging effluents with high levels of nitrates whilst phosphates were noted to be a problem with industrial effluents emanating from chemicals and edible oil refinery A. Although oil and grease were released by a good number of industries in Blantyre city, edible oil refinery 'A' was identified to have been discharging effluent with high levels of oil and grease which exceeds the local authority discharge limit on public sewer. This scenario should be a concern considering the fact that effluent from this plant ends up in the nearby stream due to poor sewer system.

The presence of metals in both periods of study varied from industry to industry depending on the activities and type of industrial production. Although cadmium, copper and nickel levels were traced in some of the industrial effluents, the levels were far below the permissible limits set by local authority standards on public sewer. The levels in other instances were even lower than the portable water guidelines suggesting that their impact on the environment would be minimal except for the fact that heavy metals can bioaccumulate to toxic levels within the environment. However levels of concern were observed at matchstick producing industry where the effluent registered high levels of chromium ($41.59 \pm 0.46\text{mg/l}$ - $56.12 \pm 1.12\text{ mg/l}$); these levels are far above local authority permissible limit (2mg/l).

Effluents from the battery, fertilizer and matchstick industries were identified to contain high levels of zinc (13.9 ± 0.46 mg/l - 30.83 ± 1.00 mg/l). The chemical, cooking oil refinery A, paint, printing and matchstick industries discharge industrial effluents that contain lead pollutant. Levels of lead in paint (1.29mg/l) and printing (2.60 mg/l) industries were higher than safe limits set by local authorities suggesting that these industries could be possible sources of lead pollution in Blantyre city.

Small and large scale wastewater treatment plants in the city of Blantyre were found effective in removing some constituents. The removal efficiency varies with wastewater treatment plant and nature of the pollutant. COD, BOD, suspended solids, oil and grease are significantly reduced by all wastewater treatment plants (WWTP) whilst metals, nitrates, sulphates, phosphates removal efficiencies varied with different treatment systems and in other case the pollutants survived through the treatment process. The removal efficiencies are adversely affected by factors such as malfunctioning equipment, insufficient capacity to handle increasing effluent load most especially in the rainy season. Constituents remaining after treatment, although subject to seasonal fluctuations, continuously are discharged to receiving streams, and thus have a continued environmental presence. Because a number of WWTPs operate within the river system of Blantyre city, especially in the upper part of the basin, wastewater inputs are additive.

The study has also revealed that industrial effluents are very complex that even effluent characteristics from industries of the similar activities differ significantly. It has further shown that different industries have different pollution potential due to the variation of levels of pollutants in the effluents. Despite that most of the industries discharge their effluent into sewerlines, they lead to pollution of the natural streams directly or indirectly. This is dependent on the state of sewerlines serving the industrial area. However, as observed in studying the quality of water in the streams, industries are not the only sources of pollutants in the streams of Blantyre as evidenced by levels variables of iron, cadmium, copper, manganese, zinc, nitrates and phosphates in the streams where they were traced well before the area of industrial activities. The variables could emanate from natural sources, diffuse sources such as agricultural activities and dumping of solid waste along the river banks.

The results in this study have further indicated gross pollution of the rivers, especially as regards COD, BOD, nutrients and some metals. The river system in Blantyre city is adversely affected with high levels of COD and BOD throughout the year despite the dilution effect experienced in

the rainy season. The levels are above the acceptable limit on surface water quality as required by Malawian Bureau of Standards. Even the nitrate and phosphate concentrations in all the streams were found to exceed the eutrophication trigger levels. Mudi stream is the most polluted of all the rivers in terms of heavy metals. It showed highest levels of cadmium, nickel and manganese which exceeded the MBS acceptable limits. The metals were observed to emanate from both industrial effluents and diffuse sources along the river bank.

4.2 RECOMMENDATIONS

In order to reduce water pollution in the City of Blantyre as shown by the results of study; it is recommended that:

- Blantyre City Assembly should review archaic trade effluent bye laws in which the discharge limits for industries are enshrined in order to formulate new standards which shall cover a wide range of pollutant parameters such as metals, sulphates, phosphates, nitrates as the practice is in other countries like Nepal, India, Singapore and Cape Town and the penalty which will be based on the levels of pollution for non compliant should be deterrent enough to discourage industries from discharging effluent of poor quality.
- Effluents should be treated to acceptable levels by the industries before discharging into the rivers or sewerlines. Industries should install pre-treatment plants. Industries whose effluent will meet the discharge standard should be given certificate of recognition for complying and where necessary they can be considered for discounts in levies such as city rates.
- Blantyre city Assembly and other environmental regulatory bodies such as Environmental affairs department, Water resources board, should be more aggressive and effective in environmental monitoring, assessment and enforcement of environmental laws and regulations.
- People should desist from cultivating and dumping waste along the river banks in order to avoid diffuse sources of pollutants to the water bodies .The most workable solution is to enforce the Town planning bye law that requires river streams reserve of 10m to15 m

where it is forbidden to carry out any activity or development in order to protect the natural environment of the streams.

- Blantyre city assembly should regularly maintain the sewerlines to ensure that effluent is not discharged into the rivers before it is treated at the major wastewater treatment plants. Regulatory bodies like Environmental Affairs Department and Water Resource Board who are mandated by law to monitor water resources should not lax enforcement on Blantyre City Assembly.
- Appropriate wastewater treatment technologies that are viable and feasible should be explored in order to improve efficiency of pre-treatment plants and major wastewater treatment plants in Blantyre city. Oxidation ponds such as those used at Limbe WWTP should be encouraged since they are cost effective and efficient in reducing the pollution load. Inclusion of tertiary treatment is required to remove metals and all other parameters that were observed to survive through the treatment system.
- Industries should adopt the concept of cleaner production which can help to reduce the strength and volume of industrial effluents and probably eliminate the use of toxic substances through substitution. The benefits do not accrue only to the industry but to the local authority through reduced costs of conveying and treating industrial effluents. Subsequently, the quality of effluent discharged from municipal sewage treatment works to the environment would improve, thereby limiting environmental damage

4.3 AREAS FOR FURTHER RESEARCH

In order to complement the study and the above proposed strategies, further research is required to

- Determine the levels of arsenic, mercury and pesticides in industrial effluents of Blantyre city.
- Identify local materials for removing heavy metals from industrial effluents.
- Establish recovery capacity of rivers in Blantyre City and effect of combined effluent from different industrial sources as a way of reducing the pollutants at source.
- Determine effects of the polluted waters emanating from Blantyre city streams on health of people using the water downstream.

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APPENDICES

Appendix 1: Guiding questions to the Key informant

Describe briefly the production process of your industry? (The researcher was taken through the actual process in the factory)

What are the main sources of effluent in your industry?

How do you dispose your effluent?

Do you pre-treat your effluent?

What type of materials or chemicals do you use in your production processes?

What type of detergents do you use for cleaning?

Do you follow any environmental guidelines in discharging the effluents?

Appendix 2: Dry season physical chemical characteristics of wastewater in industrial effluents

Levels of pH, Chlorides, Electrical conductivity, Sulphates, alkalinity, nitrates, phosphates, DO, BOD, COD, Oil and Grease, Suspended solids in industrial effluents of Blantyre city in dry season. All parameters are in mg/l except for pH and otherwise specified.

SAMPLING POINT	Cl ⁻	DO	BOD	COD	T °C	pH	Alkalinity	SS	O & G	EC mS/cm	PO ₄ ³⁻	NO ₃ ⁻	SO ₄ ²⁻
INDUSTRIAL EFFLUENTS													
Abattoirs													
Abattoir A influent	19.2± 1.3	0	1670.05 ± 12.2	4838.7 ± 23.7	24.5	7.1	540	1,887.03 ± 13.07	3.95 ± 0.035	25	26.92 ± 5.55	27.93 ± 0.28	65.74 ± 9.03
Abattoir A effluent	17.8± 0.9	0	1380.0 ± 20	5530.10 ± 30.30	24	7.4	812	403.44 ± 2.03	6.10 ± 0.059	26	24.23 ± 3.81	10.81 ± 0.45	81.06 ± 0.30
Abattoir B Influent	12.1± 0.3	0	1530 ± 6.0	1613.45 ± 8.5	27	6.2	600	1875.06 ± 32.07	3.06 ± 0.35	11	7.69 ± 0.76	37.34 ± 0.46	21.65 ± 0.25
Abattoir B effluent	17.8± 1.3	0.8	1370.00 ± 3.30	1459.68± 3.4	26	7.4	1220	809.01 ± 9.8	2.34 ± 0.021	18	39.07 ± 1.60	95.56 ± 28.0	44.32 ± 1.32
Battery													
Battery	220.0 ±9.2	2	715.04 ± 2.2	1166.64± 14.2	71	7.2	90	35 ± 0.77		22	21.54 ± 3.08	16.30 ± 2.0	6.32 ± 0.84
Brewery													
Brewery A	182.5± 8.9	3	880.01 ± 10	14515 ± 148.05	30	4.1	0	188.12 ± 4.7		10	16.54 ± 1.63	6.74 ± 0.97	3.02 ± 0.44
Brewery B	83.1±4.5	0	460.4 ± 7.4	6480.33 ± 20.07	40	4.3	0	224.8 ± 6.5		14	1.54 ± 0.0	7.36 ± 1.23	0.85 ± 0.60
Bottling													
Bottling	143.4 ± 6.7	2.6	400.83 ± 2.0	5184.63 ± 14.6	40	10.2	1420	40 ± 0.68		16	2.62 ± 1.53	8.33 ± 0.60	0.83 ± 0.0
Chemicals													
Chemicals	60.4± 3.2	0	1250.0 ± 10.5	26784.33 ± 300.09	25.6	9	2370	3,320.09 ± 31.04		57	653.84± 32.64	52.6 ± 1.53	230.64 ± 4.51
Confectionery													
Confectionery influent	39.4 ± 1.1	0	1580 ± 33.0	23328.0 ± 132.1	36	6	440	809.01 ± 11.07	502.40 ± 0.70	0	30.28 ± 1.18	70.56 ± 8.88	< dL
Confectionery effluent	38.3± 0.9	0	880.43 ± 9.2	5530.8 ± 5.7	29	5	260	12.51 ± 0.76	91.00± 0.05	11	26.9 ± 6.15	7.86 ± 0.13	< dL
Edible Cooking Oil	Cl⁻	DO	BOD	COD	T° C	pH	Alkalinity	SS	O & G	EC mS	PO₄³⁻	NO₃⁻	SO₄²⁻
Edible Oil A	22.7± 0.8	0	990.2 ± 8.5	1459.21 ± 6.6	26	7.3	1002	1,203.05 ± 24.03	650.00 ± 4.00	190000	748.46 ± 1.09	37.99 ± 0.15	33.23 ± 2.62
Edible Oil B influent	98.07 ± 4.5	0	681.0 ± 2.1	10435.44 ± 201.4	49	7.8	907	1,008.05 ± 24.07	8.96 ± 0.029	19	23.08 ± 3.26	32.47 ± 0.3	72.98 ± 0.60
Edible Oil B effluent	86.6± 3.4	1.3	210.62 ± 1.2	9523.0 ± 40.7	28	7.8	870	843 ± 5.69	5.84 ± 0.16	59	25.77 ± 9.25	27.27 ± 2.14	64.36 ± 26.63
Dairies													

Dairy A influent	90.2± 5.3	0	2004.06 ± 24.84	6480.02 ± 79.45	33	7.8	367	192.07 ± 1.12	0.76 ± 0.01	6	15.38 ± 1.33	3.00 ± 0.34	2.29 ± 0.01
Dairy A effluent	110± 7.2	0.2	1126.43± 10.09	3802.54 ± 34.01	26.5	7.7	380	392.5 ± 0.98	5.30 ± 0.02	17	13.46 ± 2.72	6.43 ± 0.53	1.66 ± 0.0
Dairy B	12.9± 1.6	0.8	1570 .32± 22.0	5875.05 ± 65.4	26	3.5	200	142 .40± 1.09	3.31 ± 0.09	0	27.69 ± 2.18	6.13 ± 0.62	< dL
Fertilizer													
Fertilizer	63.9±4.6	1	260.0 ± 3.0	1382.06 ± 8.6	27	8.3	1010	56.91 ± 0.98		45	21.54 ± 1.09	43.51 ± 1.03	256.11 ± 12.75
Matchstick													
Matches Influent	17.8 ± 2.0	3.1	855.1 ± 6.0	2851.02 ± 3.4	40	7.3	480	489.06 ± 4.01		29	0.77 ± 0.0	63.10 ±10.05	152.5 ± 16.12
Matches effluent	17.4± 1.5	5.5	310.45 ± 2.0	3629.05 ± 33.2	40	7.8	460	460.03 ± 9.08		57	10.00 ± 2.18	215.04 ± 39.64	342.81 ± 21.07
Motor Oils													
Motor Oil A	34.8± 1.0	0	240.3 ± 4.2	1306.01 ±11.12	23	7.4	650	1,800.5 ± 15.06	15.67± 0.18	24	23.85 ± 2.18	4.49 ± 0.34	40.76 ± 1.22
Motor Oil B	18.8± 0.4	2	140.05 ± 3.0	1152.3 ± 4.3	26	7.8	300	606 .11 ± 1.03	33.97± 0.043	4	1.92 ± 0.54	2.34 ± 0.0	28.30 ± 0.30
Paint													
Paint A influent	11.0 ± 0.6	0	1550.74 ± 21.0	5011.0 ± 44.9	26	9.5	970	1,004.01 ± 10.04	99.00 ± 0.14	15	11.15 ± 3.81	4.54 ± 1.44	8.40 ±0.45
Paint B effluent	12.1±0.1	1.2	1250.02 ± 3.1	7776.21 ± 22.22	25	10.6	2280	820.71 ± 7.05	23.0 ± 0.01	30	19.23 ± 0.0	12.12 ± 1.53	8.94 ± 0.0
Paint B	11.4± 0.8	0.5	220.0 ± 6.5	4838.09 ± 4.3	20	8.1	800	304 ± 4.23	10.1 ± 0.05	10	5.55± 0.52	4.97 ± 2.44	2.77 ± 0.30
Paint C influent	12.8± 0.01	0	1250.07 ± 16.0	6394.0 ± 16.5	24	7.5	430	99.07 ± 2.10	110.00 ± 0.01	6	6.30 ± 1.57	6.17 ± 1.07	8.19 ± 0.75
Paint C effluent	12.1± 0.4	0.2	680.5 ± 5.1	6048.98 ±20.9	25	7.8	550	32.1 ± 3.1	23.81± 0.80	7	1.54 ± 0.0	8.44 ± 0.31	2.87 ± 0.15
Petroleum Tankers													
Petroleum A influent	23.43± 2.7	0	140.46 ± 0.0	1166.05 ± 4.8	33	7.8	200	174.6 ± 4.71	4.94± 0.03	7	2.22 ± 0.5	10.46 ± 1.32	14.24 ± 0.74
Petroleum A effluent	9.2±0.6	0.9	140.0 ± 1.1	1080.04 ± 10.5	26.5	7	69	29.2 ± 0.99	1.11 ± 0.01	6	1.11 ± 0.01	30.41 ± 0.76	16.05 ± 0.76
Petroleum B influent	17±1.2	1.8	100.8 ± 0.9	864.01 ± 6.7	26.5	7.3	160	43.2 ± 1.32	4.92 ± 0.05	6	1.11 ± 0.0	21.10 ± 4.43	13.28 ± 0.54
Petroleum B effluent	9.2± 0.4	2.3	60.0 ± 2.2	994.77 ± 8.8	27	7.2	200	5.07 ± 0.04	2.19 ± 0.04	6	1.39 ± 0.39	11.80 ± 0.15	16.53 ± 0.6
Pharmaceuticals	Cl⁻	DO	BOD	COD	T°C	pH	Alkalinity	SS	O & G	EC mS	PO₄³⁻	NO₃⁻	SO₄²⁻
Pharmaceutical	63.3 ± 2.3	1.4	340.51± 2.4	800.09 ± 3.2	24	8	423	95.0 ± 1.54		1	0.77 ± 0.0	46.54 ± 13.16	< dL
Printing													
Printing A	36.3± 1.0	0.3	260.4 ± 0.39	720.49 ± 0.89	23	7.9	815	1776.10 ± 7.89	6.39 ± 0.03	5.1	29.23 ± 6.57	3.62 ± 0.13	20.11 ± 4.06
Printing B	13.5±0.6	1.8	240.1 ± 2.1	998 .09± 12.0	25	7.2	260	630.02 ± 5.45	2.44± 0.03	4.8	6.15 ± 3.85	1.76 ± 0.01	5.74 ± 2.41
Textile													
Textile A influent	11.4± 0.1	0	1090.0 ± 8.0	5011.5 ± 12.0	25	7.9	680	208 ± 3.22		19	1.39 ± 0.39	17.10 ± 5.20	141.19 ± 0.48

Textile B effluent	13.5± 0.3	0	920.76 ± 4.0	4320.73 ± 40.2	25	8.7	1540	80.60 ± 0.17		31	< dL	17.75 ±2.45	7.29 ± 1.06
Textile B influent	10.7±1.0	0	1420.57 ± 15.0	3629.67 ± 67.22	42	9.5	1060	308.1 ± 10.02		2	3.08 ± 2.18	2.92 ± 0.46	6.81 ± 0.56
Textile B effluent	9.9± 0.8	0.9	1240.0 ± 10.0	2678.09 ± 34.2	27	7.7	640	43.06 ± 1.04		13.3	2.31 ± 1.09	101.73 ± 6.43	6.88 ± 0.96
Textile C	31.9±1.1	0.2	680.88 ± 10.1	1532.05 ± 9.5	41	6.9	280	706 .98 ± 6.75		20	2.31 ± 0.0	10.61 ± 0.92	56.91 ± 0.15
Textile D	60.4± 3.3	2.4	77.5 ± 1.5	1152.0 ± 3.2	94	7.4	600	32.01 ± 0.35		9	8.21 ± 3.11	2.44 ± 0.41	37.64 ± 2.62

Appendix 3: Wet season physical chemical characteristics of wastewater in industrial effluents

Levels of pH, Chlorides, Electrical conductivity, Sulphates, alkalinity, nitrates, phosphates, DO, BOD, COD, Oil and Grease, Suspended solids in industrial effluents of Blantyre city in wet season. All parameters are in mg/l except for pH and otherwise specified

SAMPLING POINT	Cl	DO	BOD	COD	T° C	EC mS/cm	pH	Alkalinity	SS	O & G	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻
INDUSTRIAL EFFLUENTS													
Abattoirs													
Abattoir A influent	48.33 ± 1.34	0	670.5 ± 13.44	5357.01 ± 52.01	24	14	6.8	530	420.00 ± 10.0	3.20 ± 0.0	7.66 ± 0.0	27.14 ± 0.40	32.17 ± 0.0
Abattoir A effluent	64.60 ± 0.0	2.11	420.0 ± 0.0	3456.43 ± 34.02	26.1	12	7.1	820	56.03 ± 5.60	1.30 ± 0.0	2.89 ± 0.0	20.29 ± 0.40	16.52 ± 0.41
Abattoir B Influent	26.91 ± 0.91	0	510.0 ± 14.14	2376.05 ± 21.09	28	5.6	6.6	830	72.00 ± 7.83	7.85 ± 1.01	26.53 ± 5.81	35.14 ± 2.83	4.64 ± 0.0
Battery													
Battery	372.81 ± 3.46	0	435.0 ± 7.07	2030.54 ± 24.08	100	98	6.8	130	489.10 ± 6.63		18.14 ± 0.92	0	2.76 ± 0.41
Brewery													
Brewery A	102.90 ± 1.08	2	959.85 ± 84.64	15206.66 ± 102.08	25.3	10	3.9	0	725.01 ± 7.04		10.55 ± 0.0	61.71 ± 3.23	0
Brewery B	112.21 ± 2.20	0.13	519.5 ± 55.86	4147.67 ± 42.79	34	55	12	2780	260.00 ± 8.00		9.75 ± 1.33	0	0
Bottling													
Bottling	63.90 ± 0.0	2.54	399.45 ± 29.07	2592.32 ± 18.03	26.9	9.2	10.7	610	53.66 ± 2.34		1.73 ± 0.0	2.57 ± 0.40	3.33 ± 1.23
Chemicals													
Chemicals	95.93 ± 0.63	2.14	265.0 ± 7.07	15532 ± 112.04	26.6	21	6.2	180	1325.55 ± 25.5		17.10 ± 0.07	82.57 ± 6.06	129.13 ± 10.45
Confectionery													
Confectionery influent	74.61 ±	2.23	900.01 ±	5530.00 ± 5.50	27	5	5.7	200	365.00 ± 5.02	500.0 ± 18.9	19.94 ± 0.0	23.43 ± 4.04	4.35 ± 0.09

	3.21		28.28										
Confectionery effluent	102.90 ± 0.85	1.86	840.1 ± 0.14	3024.40 ± 24.04	27.5	5	5.4	220	192.0 ± 6.50	58.70 ± 1.65	6.50 ± 1.02	30.37 ± 4.44	34.20 ± 0.0
Edible Cooking Oil	CI	DO	BOD	COD	T° C	EC mS	pH	Alkalinity	SS	O & G	NO₃⁻	PO₄³⁻	SO₄²⁻
Edible Oil A	28.00 ± 0.0	0	969.35 ± 69.93	15898.96 ± 89.02	37.1	7	3	0	71490.00 ± 400	223.79 ± 9.02	55.84 ± 1.27	203.14 ± 9.29	2059.42 ± 39.97
Edible Oil B influent	66.01 ± 2.76	2.06	950.0 ± 14.14	2506.66 ± 42.08	25.4	6	6.4	290	424.74 ± 4.24	103.00 ± 6.37	8.67 ± 1.84	4.86 ± 0.40	3.77 ± 0.82
Edible Oil B effluent	88.80 ± 0.01	1.35	378.52 ± 26.18	5789.77 ± 66.54	23.1	26	9.1	1070	264.08 ± 8.86	10.93 ± 0.37	15.59 ± 1.66	18.00 ± 2.83	148.91 ± 73.27
Dairies													
Dairy A influent	131.40 ± 5.6	0.93	520.0 ± 11.3	4493.00 ± 26.74	31.1	6.8	4.1	0	244.0 ± 10.02	446.67 ± 12.05	15.17 ± 0.0	2.00 ± 1.21	2.83 ± 0.72
Dairy A effluent	49.71 ± 0.03	0	420.0 ± 0.0	6048.06 ± 19.22	27	5.6	5.7	310	348.04 ± 12.06	55.67 ± 1.34	11.12 ± 0.0	5.43 ± 1.21	5.51 ± 0.0
Dairy B	18.1 ± 1.02	1.08	780.45 ± 29.06	2938.04 ± 14.02	25.9	2.6	6.5	270	84.00 ± 4.00	15.67 ± 1.79	11.20 ± 2.96	4.00 ± 1.62	1.45 ± 0.20
Fertilizer													
Fertilizer	71.02 ± 2.31	0	220.0 ± 0.0	1642.00 ± 10.05	26.3	12	8.9	1050	55.46 ± 1.08		29.45 ± 0.0	3.43 ± 0.0	205.07 ± 32.38
Matchstick													
Matches Influent	32.70 ± 0.93	8.37	255.02 ± 7.07	2506.05 ± 15.85	44.4	67	7.6	410	270.0 ± 5.60		5.32 ± 0.22	2.86 ± 0.81	54.78 ± 2.05
Matches effluent	44.69 ± 1.06	9.64	182.5 ± 3.54	3456.32 ± 26.88	40	87	7.5	460	650.88 ± 14.24		6.94 ± 0.0	7.72 ± 1.21	170.72 ± 0.0
Motor Oils													
Motor Oil A	22.70 ± 0.0	0.6	205.4 ± 6.22	2246.22 ± 18.12	23.2	2.8	7.3	310	40.0 ± 1.00	32.00 ± 0.76	24.42 ± 0.0	3.43 ± 0.0	11.09 ± 2.77
Motor Oil B	29.11 ± 0.3	1.66	117.5 ± 10.61	778.56 ± 12.02	24.5	3.2	7.1	250	4.02 ± 0.01	15.70 ± 0.85	18.53 ± 0.74	0	8.04 ± 0.51
Paint													
Paint A influent	14.23 ± 0.43	1.34	600.0 ± 0.0	5357.56 ± 25.98	28.2	6.4	10.1	820	697.11 ± 4.78	49.30 ± 1.72	1.88 ± 0.0	5.43 ± 1.21	0
Paint B effluent	12.80 ± 0.90	0	450 ± 42.43	4666.66 ± 12.02	25.9	4.2	9.3	500	270.01 ± 9.06	7.28 ± 0.23	6.91 ± 0.03	5.14 ± 2.42	0
Paint B	17.80 ± 0.0	0.5	890.77 ± 40.63	3974.01 ± 9.84	22	4.2	7	490	119.78 ± 5.46	11.43 ± 1.78	3.03 ± 0.0	0	1.23 ± 0.10
Paint C influent	18.50 ± 0.05	0	920.5 ± 55.23	6221.11 ± 7.73	25.3	3.1	6.8	300	125.00 ± 0.98	28.95 ± 0.68	1.30 ± 0.0	0.57 ± 0.0	36.81 ± 0.61
Paint C effluent	17.00 ± 0.01	0	490.9 ± 9.60	3812.04 ± 21.02	27.3	3	7	290	125.04 ± 3.56	65.64 ± 1.99	12.31 ± 0.0	5.14 ± 0.0	12.54 ± 0.72
Petroleum Tankers													
Petroleum A influent	14.20 ± 0.0	0	125 ± 7.07	691.72 ± 4.28	23.2	1.5	6.9	110	48.00 ± 3.00	8.33 ± 0.43	9.18 ± 3.78	0	1.23 ± 0.72
Petroleum A effluent	14.91 ± 0.01	0	110.0 ± 0.0	605.05 ± 3.55	23.3	0.7	6.8	90	37.66 ± 1.64	6.17 ± 0.38	6.21 ± 0.61	0	0.43 ± 0.20
Petroleum B influent	19.20 ± 0.07	1.6	344.9 ± 7.78	1425.50 ± 42.77	24.3	2.3	7.4	200	240.05 ± 5.55	14.14 ± 0.53	6.29 ± 2.55	0	14.35 ± 0.61
Petroleum B effluent	14.20 ± 0.0	1.2	184.87 ± 7.30	734.06 ± 7.88	25	1.8	7.2	180	146.44 ± 6.62	6.71 ± 0.40	6.14 ± 1.12	0	11.30 ± 0.20

Pharmaceuticals	Cl	DO	BOD	COD	T° C	EC mS	pH	Alkalinity	SS	O & G	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻
Pharmaceutical	65.33 ± 0.43	4.02	585.0 ± 21.21	7680.22 ± 115.08	24.4	5.5	6.3	340	212.00 ± 10.00		14.6 ± 0.0	1.71 ± 0.0	9.42 ± 0.20
Printing													
Printing A	34.12 ± 0.20	2.91	360.41 ± 2.77	3370.03 ± 44.02	25.3	3.1	6.5	190	195.05 ± 2.00	39.12 ± 8.07	10.69 ± 3.27	35.43 ± 2.42	0
Printing B	17.80 ± 0.02	1.17	350.46 ± 2.74	1901.00 ± 5.50	26.5	2.4	6.5	280	834.20 ± 16.02	68.00 ± 1.90	3.38 ± 0.53	8.86 ± 0.40	2.32 ± 0.61
Textile													
Textile A influent	26.90 ± 0.0	2.17	860.0 ± 56.57	4666.05 ± 13.06	22.5	6.2	7.6	840	52.00 ± 0.00		20.52 ± 4.90	4.00 ± 0.0	2.17 ± 0.20
Textile B effluent	24.91 ± 0.06	0.4	730.05 ± 42.39	2765.02 ± 33.13	24	7.1	7.8	960	40.04 ± 4.40		6.72 ± 0.10	1.71 ± 0.81	0
Textile B influent	26.30 ± 0.83	0	581.01 ± 8.34	3974.07 ± 12.01	26	2.8	7.1	360	61.01 ± 3.21		2.02 ± 0.0	2.00 ± 0.40	10.43 ± 0.0
Textile B effluent	17.81 ± 0.01	0	320.0 ± 0.0	5530.05 ± 25.03	25	3	6.9	330	55.5 ± 6.5		3.11 ± 0.10	3.14 ± 1.21	23.77 ± 0.0
Textile C	76.70 ± 0.0	0.27	550.04 ± 7.06	3024.21 ± 8.96	37.8	14	6.4	220	124.11 ± 4.31		10.69 ± 2.25	34.00 ± 6.87	209.13 ± 0.20
Textile D	42.63 ± 0.03	0	21.0 ± 1.41	907.02 ± 7.70	37	10	7.7	390	95.91 ± 1.06		5.20 ± 2.04	2.57 ± 0.40	57.61 ± 7.48

Appendix 4: Levels of metals in industrial effluents in the dry season

All parameters are in mg/l

SAMPLING POINT	Cu	Ni	Cd	Cr	Pb	Fe	Zn	Mn	K	Ca
INDUSTRIAL EFFLUENTS										
Abattoirs										
Abattoir A influent	<dL	0.333 ± 0.16	0.065 ± 0.006	< dL	< dL	6.01 ± 0.95	0.20 ± 0.01	0.116 ± 0.007	20.11 ± 0.01	16.82 ± 0.33
Abattoir A effluent	<dL	0.222 ± 0.0	0.060 ± 0.005	< dL	< dL	2.13 ± 0.17	0.16 ± 0.01	0.254 ± 0.013	19.96 ± 0.001	19.47 ± 0.42
Abattoir B Influent	0.272 ± 0.0	<dL	< dL	< dL	< dL		0.07 ± 0.01	0.455 ± 0.016	19.94 ± 0.01	11.94 ± 0.08
Abattoir B effluent	<dL	< dL	< dL	< dL	< dL	1.01 ± 0.02	0.129 ± 0.003	< dL	19.94 ± 0.0	5.41 ± 0.0
Battery										
Battery	0.026 ± 0.013	< dL	0.019 ± 0.001	< dL	< dL	1.57 ± 0.06	13.9 ± 0.46	0.523 ± 0.023	8.81 ± 0.13	23.35 ± 0.08
Brewery										
Brewery A	0.048 ± 0.0	< dL	< dL	< dL	< dL	< dL	0.133 ± 0.01	0.186 ± 0.050	20.02 ± 0.01	13.24 ± 1.25
Brewery B	0.04 ± 0.011	< dL	< dL	< dL	< dL	< dL	0.57 ± 0.13	0.403 ± 0.006	19.94 ± 0.02	13.76 ± 0.83
Bottling										
Bottling	0.136 ± 0.033	< dL	< dL	< dL	< dL	< dL	0.21 ± 0.02	0.322 ± 0.006	7.67 ± 0.11	10.88 ± 1.58
Chemicals										
Chemicals	0.552 ± 0.057	0.222 ± 0.001	< dL	< dL	0.143	5.48 ± 0.92	1.00 ± 0.05	0.839 ± 0.016	19.93 ± 0.03	18.88 ± 1.08

Confectionery										
Confectionery influent	0.128 ± 0.0	0.444 ± 0.001	0.035± 0.004	< dL	< dL	1.313 ± 0.06	14.91 ± 0.08	4.271± 0.092	19.99 ± 0.0	126.53 ± 1.25
Confectionery effluent	0.048 ± 0.0	< dL	0.007 ± 0.004	< dL	< dL	0.53 ± 0.16	1.24 ± 0.09	< dL	9.08 ± 0.61	18.76 ± 0.92
Edible Cooking Oil										
Edible Oil A	0.657 ± 0.045	1.11 ± 0.31	< dL	< dL	0.143	4.80 ± 0.42	2.45 ± 0.06	1.458 ± 0.100	19.86 ± 0.01	24.76 ± 1.75
Edible Oil B influent	0.216 ± 0.034	< dL	0.013 ± 0.004	< dL	< dL	3.26 ± 0.03	0.90 ± 0.004	0.420 ± 0.096	19.96 ± 0.0	6.06 ± 1.25
Edible Oil B effluent	0.313 ± 0.011	< dL	0.014± 0.002	< dL	< dL	< dL	0.41 ± 0.002	0.476 ± 0.034	19.96 ± 0.0	6.65 ± 0.08
Dairies										
Dairy A influent	0.192 ± 0.0	< dL	< dL	< dL	< dL	0.82 ± 0.01	0.053 ± 0.02	0.161 ± 0.002	19.98 ± 0.04	20.29 ± 0.08
Dairy A effluent	0.272 ± 0.068	< dL	< dL	< dL	< dL	< dL	< dL	0.083 ± 0.015	20.02 ± 0.0	22.88 ± 0.08
Edible B	0.088 ± 0.034	< dL	0.015 ± 0.001	< dL	< dL	0.97 ± 0.01	< dL	< dL	8.81 ± 0.07	22.12 ± 0.17
Fertilizer	Cu	Ni	Cd	Cr	Pb	Fe	Zn	Mn	K	Ca
Fertilizer	0.216 ± 0.079	< dL	0.019 ± 0.001	< dL	< dL	1.49 ± 0.03	14.14 ± 0.25	< dL	20.01 ± 0.0	17.88 ± 0.0
Matchstick										
Matches Influent	0.248 ± 0.079	3.09± 0.079	1	17.81± 0.10	< dL	< dL	17.99 ± 0.13	0.350 ± 0.0	20.06 ± 0.0	18.88 ± 1.08
Matches effluent	0.216 ± 0.011	< dL	< dL	41.59 ± 0.46	< dL	1.28 ± 0.02	18.97 ± 0.01	0.134 ± 0.0	20.47 ± 0.0	19.82 ± 0.25
Motor Oils										
Motor Oil A	0.096 ± 0.0	< dL	< dL	< dL	< dL	2.00 ± 0.03	0.91 ± 0.08	0.212 ± 0.055	19.99 ± 0.03	22.71 ± 0.50
Motor Oil B	0.208 ± 0.0	< dL	0.025 ± 0.004	< dL	< dL	< dL	0.204 ± 0.03	0.318 ± 0.025	5.63 ± 0.12	21.59 ± 0.08
Paint										
Paint A influent	0.016 ± 0.0	< dL	0.010 ± 0.004	< dL	1.81 ± 0.39	< dL	0.15 ± 0.05	0.394 ± 0.012	4.77 ± 0.88	44.00 ± 0.0
Paint B effluent	0.192 ± 0.045	< dL	0.002 ± 0.0	< dL	1.22± 0.65	< dL	0.16 ± 0.01	0.269 ± 0.011	6.29 ± 0.24	27.65 ± 0.0
Paint B	0.184 ± 0.057	< dL	0.026± 0.005	< dL	< dL	< dL	0.10 ± 0.002	0.405 ± 0.012	7.75 ± 0.02	83.06 ± 0.33
Paint C influent	0.489 ± 0.03	< dL	< dL	< dL	1.76 ± 0.10	< dL	0.11 ± 0.02	0.423 ± 0.049	6.74 ± 0.13	70.65 ± 0.42
Paint C effluent	2.00 ± 0.011	< dL	< dL	< dL	1.29 ± 0.0	< dL	0.07 ± 0.01	0.602 ± 0.031	6.96 ± 0.08	57.18 ± 0.0
Petroleum Tankers										
Petroleum A influent	<dL	< dL	< dL	< dL	< dL	0.28 ± 0.04	< dL	< dL	9.63 ± 0.05	25.12 ± 0.42
Petroleum A effluent	<dL	< dL	< dL	< dL	< dL	0.43 ± 0.02	< dL	< dL	9.37 ± 0.05	26.35 ± 0.33
Petroleum B influent	<dL	< dL	< dL	< dL	< dL	1.13 ± 0.00	1.12 ± 0.01	< dL	5.32 ± 0.15	19.88 ± 1.16
Petroleum B effluent	<dL	< dL	< dL	< dL	< dL	1.37 ± 0.03	0.57 ± 0.01	< dL	4.59 ± 0.04	16.53 ± 0.08
Pharmaceuticals										
Pharmaceutical	0.288 ± 0.023	< dL	< dL	< dL	< dL	< dL	1.20 ± 0.04	0.151 ± 0.001	9.19 ± 0.19	28.76 ± 0.08
Printing										
Printing A	0.801 ± 0.022	< dL	0.025 ± 0.002	< dL	0.286 ± 0.0	3.25 ± 0.10	3.18 ± 0.09	0.945 ± 0.049	7.08 ± 0.95	20.65 ± 0.25
Printing B	0.208 ± 0.0	< dL	0.034 ± 0.001	< dL	2.60 ± 0.02	1.83± 0.03	0.27 ± 0.002	0.205 ± 0.013	5.82 ± 0.14	14.18 ± 2.75

Textile										
Textile A influent	0.369 ± 0.09	0.222 ± 0.0	< dL	< dL	< dL	0.75 ± 0.03	0.218 ± 0.06	< dL	9.43 ± 0.69	11.82 ± 0.25
Textile B effluent	0.224 ± 0.0	< dL	< dL	< dL	< dL	0.41 ± 0.15	< dL	< dL	19.97 ± 0.0	20.06 ± 0.08
	Cu	Ni	Cd	Cr	Pb	Fe	Zn	Mn	K	Ca
Textile B influent	0.801 ± 0.0	< dL	0.041 ± 0.003	< dL	< dL	< dL	0.10 ± 0.002	0.289 ± 0.002	19.92 ± 0.0	17.12 ± 0.25
Textile B effluent	1.16 ± 0.034	< dL	0.028 ± 0.004	< dL	< dL	< dL	0.22 ± 0.01	0.291 ± 0.012	19.96 ± 0.0	21.35 ± 0.75
Textile C	0.144 ± 0.045	< dL	0.034 ± 0.003	< dL	< dL	< dL	0.08 ± 0.004	0.168 ± 0.011	19.95 ± 0.01	11.12 ± 0.25
Textile D	0.080 ± 0.022	< dL	< dL	< dL	< dL	0.52 ± 0.08	0.09 ± 0.004	0.281 ± 0.001	9.67 ± 1.33	16.94 ± 0.17

Appendix 5: Levels of metals in industrial effluents in the wet season

All parameters are in mg/l

SAMPLING POINT	Cd	Cr	Cu	Fe	Mn	Ni	Zn	Pb	Ca	K
INDUSTRIAL EFFLUENTS										
Abattoirs										
Abattoir A influent	<dL	<dL	0.01 ± 0.004	3.27 ± 0.72	0.359 ± 0.011	0.453 ± 0.115	0.492 ± 0.01	<dL	9.41 ± 1.66	15.54 ± 0.14
Abattoir A effluent	<dL	<dL	0	2.68 ± 0.16	0.333 ± 0.019	0.383 ± 0.014	0.103 ± 0.04	<dL	16.29 ± 0.08	13.82 ± 0.03
Abattoir B Influent	<dL	<dL	0	0.91 ± 0.05	0.112 ± 0.023	<dL	<dL	<dL	4.71 ± 0.17	15.02 ± 0.03
Abattoir B effluent		<dL	0			<dL	<dL	<dL		15.02 ± 0.003
Battery										
Battery	<dL	<dL	0.034 ± 0.0	1.70 ± 0.06	9.01 ± 0.15	<dL	30.83 ± 1.0	<dL	42.00 ± 0.33	13.13 ± 0.01
Brewery										
Brewery A	<dL	<dL	0.034 ± 0.0	6.13 ± 0.12	0.075 ± 0.023	<dL	0.27 ± 0.01	<dL	7.53 ± 0.33	15.62 ± 0.07
Brewery B	<dL	<dL	0.034 ± 0.0	0.094 ± 0.017	<dL	<dL	<dL	<dL	6.00 ± 0.0	11.94 ± 0.02
Bottling										
Bottling	<dL	<dL	0	0.959 ± 0.05	<dL	<dL	<dL	<dL	7.82 ± 0.75	6.57 ± 0.20
Chemicals			0			<dL			Not done	
Chemicals	<dL									
Confectionery	<dL	<dL	0.034 ± 0.0	14.08 ± 0.03	0.891 ± 0.269	<dL	0.23	<dL	63.29 ± 0.50	10.10 ± 0.17
Confectionery influent										
Confectionery effluent	<dL	<dL	0	0.107 ± 0.01	<dL	<dL	0.043 0.02	<dL	2.12 ± 0.50	16.78 ± 0.01
Edible Cooking Oil										
Edible Oil A	<dL	<dL	0.30 ± 0.021	15.44 ± 0.36	0.557 ± 0.025	<dL	0.377 ± 0.164	<dL	17.82 ± 1.25	16.06 ± 0.0
Edible Oil B influent	<dL	<dL	0	1.14 ± 0.12	0.011 ± 0.001	<dL	0.52 ± 0.043	<dL	4.29 ± 0.08	5.54 ± 0.13
Edible Oil B effluent	<dL	<dL	0	3.20 ± 0.17	0.161 ± 0.054	<dL	0.40 ± 0.08	<dL	4.47 ± 0.17	11.71 ± 0.15
Dairies										

Dairy A influent	<dL	<dL	0	0.207 ± 0.03	<dL	<dL	<dL	<dL	75.88 ± 3.49	10.13 ± 0.18
Dairy A effluent	<dL	<dL	0	1.36 ± 0.22	<dL	<dL	<dL	<dL	16.59 ± 0.17	12.02 ± 0.01
Dairy B	<dL	<dL	0	0		<dL	<dL	<dL	17.88 ± 0.67	7.67 ± 0.05
Fertilizer	Cd	Cr	Cu	Fe	Mn	Ni	Zn	Pb	Ca	K
Fertilizer	<dL	<dL	0	1.21 ± 0.08	0.026 ± 0.0	<dL	<dL	<dL	54.35 ± 1.16	12.25 ± 0.03
Matchstick										
Matches Influent	<dL	36.26 ± 0.25	0	0.319 ± 0.11	<dL	<dL	10.32 ± 2.99	0.465 ± 0.07	15.76 ± 0.50	20.00 ± 0.0
Matches effluent	<dL	56.12 ± 1.12	0	0.840 ± 0.182	<dL	<dL	15.51 ± 4.50	0.465 ± 0.07	10.88 ± 0.08	20.00 ± 0.0
Motor Oils										
Motor Oil A	<dL	<dL	0.119 ± 0.012	8.996 ± 0.001	0.209 ± 0.064	<dL	0.012 ± 0.0	<dL	6.76 ± 1.41	9.38 ± 0.07
Motor Oil B	<dL	<dL	0	0.856 ± 0.235	0.121 ± 0.012	<dL	0.107 ± 0.02	<dL	18.00 ± 1.00	5.69 ± 0.03
Paint										
Paint A influent	<dL	<dL	0	0.254 ± 0.051	<dL	<dL	<dL	<dL	12.41 ± 0.92	8.42 ± 0.38
Paint B effluent	<dL	<dL	0	0.049 ± 0.0	<dL	<dL	<dL	<dL	23.76 ± 0.83	8.23 ± 0.21
Paint B	<dL	<dL	0	0.563 ± 0.047	0.037 ± 0.001	<dL	<dL	<dL	46.00 ± 0.83	8.64 ± 0.14
Paint C influent	<dL	<dL	0.034 ± 0.0	1.12 ± 0.03	0.278 ± 0.018	<dL	0.285 ± 0.0	<dL	33.35 ± 2.25	7.24 ± 0.13
Paint C effluent	<dL	<dL	0.055 ± 0.002	0.902 ± 0.112	0.24 ± 0.024	<dL	0.233 ± 0.039	<dL	33.71 ± 0.75	7.25 ± 0.25
Petroleum Tankers										
Petroleum A influent	<dL	<dL	0	3.21 ± 0.52	<dL	<dL	<dL	<dL	4.94 ± 0.33	3.20 ± 0.13
Petroleum A effluent	<dL	<dL	0	1.66 ± 0.02	<dL	<dL	<dL	<dL	4.18 ± 1.41	2.71 ± 0.08
Petroleum B influent	<dL	<dL	0	0.733 ± 0.02	<dL	<dL	<dL	<dL	14.06 ± 0.08	1.95 ± 0.01
Petroleum B effluent	<dL	<dL	0	0.879 ± 0.025	<dL	<dL	<dL	<dL	13.29 ± 0.50	2.34 ± 0.15
Pharmaceuticals										
Pharmaceutical	<dL	<dL	0	1.59 ± 0.02	<dL	<dL	0.076 ± 0.0	<dL	53.88 ± 0.17	12.51 ± 0.09
Printing										
Printing A	<dL	<dL	0.102 ± 0.048	2.02 ± 0.47	0.269 ± 0.023	<dL	0.168 ± 0.03	<dL	4.88 ± 0.08	8.84 ± 0.22
Printing B	<dL	<dL	0.273 ± 0.024	7.80 ± 0.47	0.367 ± 0.021	<dL	0.272 ± 0.01	0.233 ± 0.0	27.71 ± 0.42	7.45 ± 0.04
Textile										
Textile A influent	<dL	<dL	0.341 ± 0.0	0.258 ± 0.02	<dL	<dL	<dL	<dL	8.82 ± 0.0	13.46 ± 0.02
Textile B effluent	<dL	<dL	0.546 ± 0.048	0.859 ± 0.05	<dL	<dL	<dL	<dL	10.24 ± 0.50	14.01 ± 0.07
Textile B influent	<dL	<dL	0.102 ± 0.0	0.061 ± 0.021	0.029 ± 0.0	0.10 ± 0.02	0.26 ± 0.0	<dL	17.00 ± 1.75	8.26 ± 0.05
	Cd	Cr	Cu	Fe	Mn	Ni	Zn	Pb	Ca	K
Textile B effluent	<dL	<dL	0.137 ± 0.0	0.503 ± 0.03	0.001 ± 0.0	0.07 ± 0.01	0.36 ± 0.01	<dL	16.76 ± 0.42	8.35 ± 0.03
Textile C	<dL	<dL	0.051 ± 0.012	0.673 ± 0.084	0.106 ± 0.005	<dL	0.351 ± 0.03	<dL	28.71 ± 0.0	9.79 ± 0.15
Textile D	<dL	<dL	0.358 ± 0.012	0.074 ± 0.03	<dL	<dL	<dL	<dL	27.24 ± 0.75	9.63 ± 0.12

Appendix 6: Public sewer permissible limits and surface water standards

General standards for water course (Malawi & WHO) & 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.

No	Parameter	Tolerance limit- Public sewer					Water course	
		Blantyre	Cape town	India	Nepal	Singapore	Malawi standard	WHO
1	Temperature °C	40	40	45	45	45	5.0-9.5	6.5-8.5
2	pH value	6.5-9.0	5.5-12.0	5.5-9.0	5.5-9.0	6-9		
3	BOD ₅ ²⁰	400	-	500	400	400	20	-
4	COD	1000	5000		1000	600	60	-
5	Suspended solids	-	1000	600	600	400	-	-
6	Chloride	-	1500	600	1000	1000	400	250
7	Sulphate	-	1500	-	500	1000	400	250
8	Grease and Oil	10	400	100	50	60		
9	Nitrate (NO ₃ ⁻)	-	-	-	50	-	10.0	50
10	Phosphate (PO ₄ ³⁻)	-	25	-	-	-	-	0.5
11	Dissolved Oxygen	>1.0	-	-	-	-	-	-
12	Iron	-	50	-	-	50	0.2	0.3
13	Manganese	-	-	-	-	10	0.1	0.4
14	Cadmium	-	5	2	2.0	1	0.005	0.003
15	Chromium	-	10	2	2.0	5	0.1	0.05
16	Copper	-	20	3	3.0	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	10	5.0	3.0
20	Calcium	-	-	-	-	-	150	-
21	Potassium	-	-	-	-	-	50	-

Appendix 7: Physical chemical characteristics of wastewater in major wastewater treatment plant in Blantyre City

All parameters are in mg/l except for pH and otherwise specified

SAMPLING POINT	Cl ⁻	DO	BOD	COD	T°C	pH	Alkalinity	SS	O & G	EC mS	PO ₄ ³⁻	NO ₃ ⁻	SO ₄ ²⁻
DRY SEASON													
Blantyre sewage plant													
Raw	34.8±0.9	0	440.06 ± 5.6	1642.3 ± 12.5	27	6.6	400	210.02 ± 4.05	0.073 ± 0.001	7	7.41 ± 1.04	44.80 ± 18.67	46.45 ± 1.60
Final	33.4±1.1	1.2	58.0 ± 3.10	691.01 ± 5.6	27	7.3	610	232.08 ± 1.42	0.018 ± 0.00	9	10.74 ± 0.52	152.92 ± 35.66	44.11 ± 2.33
Mudi stream above	48.3±2.3	3.5	10.50 ± 0.1	821.91 ± 3.2	26	7.6	860	51.45 ± 2.31	0.046 ± 0.003	13	0.77 ± 0.02	25.78 ± 1.93	3.12 ± 0.33
Mudi stream below	40.8 ± 1.1	1.5	21.0 ± 1.2	1037.0 ± 21.1	27	7.5	750	14.00 ± 0.0	0.274 ± 0.007	11	8.46 ± 2.31	3.13 ± 0.0	6.70 ± 0.45
Limbe Sewage plant													
Raw	53.3 ± 4.3	0	740.0 ± 10.1	1296 ± 102.1	31	7.4	410	220.0 ± 0.0	1.59 ± 0.012	10	21.54 ± 0.0	5.27 ± 0.03	34.86 ± 0.96
Final	76.0 ± 5.1	4.3	50.5 ± 1.0	777.05 ± 17.67	30	9.8	440	16.04 ± 0.19	0.039 ± 0.001	1	4.44 ± 1.05	17.58 ± 0.11	30.833 ± 1.77
Limbe stream above	53.3 ± 3.0	3.6	17.01 ± 0.71	671.22 ± 30.2	26	8.2	380	1.0 ± 0.0	1.59 ± 0.004	11	22.69 ± 2.71	17.21 ± 1.99	10.35 ± 0.67
Limbe stream below	51.5 ± 1.1	3.8	28.0 ± 1.2	812.01 ± 8.9	27	8.1	400	4.01 ± 0.01	0.20 ± 0.002	11	18.62 ± 1.19	26.08 ± 3.52	12.43 ± 0.52
Soche sewage plant													
Raw	44.0 ± 1.0	0	490.0 ± 9.8	883.30 ± 12.5	26	7.1	560	157.0 ± 2.32	1.84 ± 0.06	20	10.0 ± 2.36	12.45 ± 2.30	20.93 ± 0.36
Final	46.2 ± 2.3	0	24.82 ± 0.6	353 ± 4.31	26	7.3	450	101.65 ± 5.64	0.34 ± 0.003	16	12.5 ± 3.54	9.42 ± 0.77	22.66 ± 2.02
Mlambalala stream above	41.2 ± 0.9	2.7	14.5 ± 1.2	778 ± 2.1	26	7.3	440	30.05 ± 1.23	0.016 ± 0.001	5	< dL	22.27 ± 0.28	31.11 ± 2.11
Mlambalala stream below	48.3 ± 3.0	1.4	32.50 ± 3.1	1037.91 ± 10.1	26.5	7.4	470	22.37 ± 1.60	0.12 ± 0.002	12	< dL	21.10 ± 4.92	17.92 ± 0.21
WET SEASON													
Blantyre Sewage Plant													
Raw	36.9 ± 1.3	1.4	510 ± 14.14	691.11 ± 5.03	25.8	6.7	400	29.01 ± 0.0	8.73 ± 0.19	4.5	0.57 ± 0.0	84.47 ± 2.15	8.26 ± 3.69
Final	36.20 ± 0.89	2.6	450 ± 42.43	503.01 ± 0.91	26.6	7	370	25.91 ± 2.03	3.61 ± 0.09	4.1	0	32.37 ± 0.0	7.75 ± 0.10
Mudi stream above	37.61 ± 0.5	2.9	35.0 ± 1.41	432.00 ± 0.0	25.7	7.8	340	10.00 ± 0.0	7.55 ± 0.45	3.8	4.29 ± 1.21	9.39 ± 0.0	5.65 ± 0.41
Mudi stream below	29.80 ± 0.0	3.5	17.01 ± 1.41	374.00 ± 3.050	26.3	7.7	320	43.01 ± 4.01	0.83 ± 0.01	3.8	1.43 ± 0.40	12.30 ± 0.62	7.25 ± 0.82
	Cl ⁻	DO	BOD	COD	T°C	pH	Alkanlinity	SS	O & G	EC mS	PO ₄ ³⁻	NO ₃ ⁻	SO ₄ ²⁻
Limbe Sewage plant													
Raw	48.29 ± 1.01	1.9	810.5 ± 41.72	821.32 ± 10.06	26.1	7.1	280	268.45 ± 3.56	3.85 ± 0.97	3.4	2.29 ± 0.81	61.68 ± 0.0	8.48 ± 0.72

Final	34.10 ± 0.0	4.7	63.0 ± 4.24	778.56 ± 19.20	27.1	9.1	240	214.0 ± 2.96	0.23 ± 0.03	3.9	0	30.58 ± 10.35	2.61 ± 0.41
Limbe stream above	35.50 ± 0.0	2.1	23.5 ± 0.71	461.33 ± 7.33	27	7.4	210	18.01 ± 1.11	0.25 ± 0.01	3	1.71 ± 0.0	53.33 ± 0.0	13.77 ± 0.62
Limbe stream below	44.68 ± 0.54	2.2	25.5 ± 0.71	403.01 ± 5.67	27	7.5	230	33.00 ± 0.0	0.37 ± 0.01	3.2		37.64 ± 2.55	13.19 ± 0.41
Soche sewage plant													
Raw	40.51 ± 0.01	0	760.0 ± 0.0	907.00 ± 10.05	26	7	360	40.0 ± 0.0	7.23 ± 0.91	3.9	1.43 ± 0.40	33.09 ± 0.0	14.49 ± 0.82
Final	39.10 ± 0.0	1.2	33.9 ± 2.69	734.90 ± 16.55	25.4	7.3	180	8.02 ± 0.02	2.1 ± 0.86	3.3	1.71 ± 0.0	218.92 ± 10.45	17.25 ± 0.41
Mlambalala stream above	36.92 ± 0.02	1.8	11.1 ± 1.56	518.17 ± 8.23	25.6	7.5	290	4.01 ± 0.65	1.26 ± 0.07	3.8	0.57 ± 0.0	50.06 ± 7.68	11.09 ± 0.92
Mlambalala stream below	48.30 ± 0.0	1.4	21.5 ± 2.12	432.00 ± 4.00	25.5	7.1	210	10.00 ± 1.00	3.89 ± 0.63	3.8	2.29 ± 1.62	88.15 ± 3.27	9.13 ± 1.02

Appendix 8: Levels in of metals WWTP

All parameters are in mg/l

SAMPLING POINT	Cu	Ni	Cd	Cr	Pb	Fe	Zn	Mn	K	Ca
TREATMENT PLANTS										
Blantyre Sewage Plant										
Raw	0.040 ± 0.011	< dL	< dL	< dL	< dL	< dL	0.035 ± 0.01	0.378 ± 0.049	19.95 ± 0.01	21.76 ± 0.17
Final	< dL	< dL	< dL	< dL	< dL	< dL	0.044 ± 0.01	0.399 ± 0.077	19.96 ± 0.0	21.65 ± 0.0
Mudi stream above	< dL	< dL	0.40 ± 0.0	< dL	< dL	< dL	< dL	0.411 ± 0.006	19.91 ± 0.02	29.76 ± 0.33
Mudi stream below	< dL	< dL	0.039 ± 0.006	< dL	< dL	< dL	0.02 ± 0.002	0.414 ± 0.058	19.95 ± 0.02	29.12 ± 0.42
Limbe Sewage plant										
Raw	0.104 ± 0.01	< dL	< dL	< dL	< dL	< dL	0.45 ± 0.02	0.479 ± 0.068	19.94 ± 0.0	17.71 ± 0.08
Final	0.096 ± 0.0	< dL	0.014 ± 0.004	< dL	< dL	1.00 ± 0.02	0.017 ± 0.02	0.383 ± 0.042	19.93 ± 0.0	19.12 ± 0.25
Limbe stream above	< dL	0.222 ± 0.0	0.022 ± 0.0	< dL	< dL	< dL	0.86 ± 0.01	0.394 ± 0.058	19.33 ± 0.25	25.18 ± 1.00
Limbe stream below	< dL	< dL	< dL	< dL	< dL	2.17 ± 0.07	0.92 ± 0.01	0.475 ± 0.035	10.28 ± 0.64	24.82 ± 0.0
Soche sewage plant										
Raw	< dL	< dL	< dL	< dL	< dL	0.79 ± 0.01	0.15 ± 0.01	< dL	19.99 ± 0.0	12.47 ± 0.17
Final	< dL	< dL	0.002 ± 0.001	< dL	< dL	1.42 ± 0.06	< dL	< dL	19.99 ± 0.0	11.12 ± 0.08
Mlambalala stream above	< dL	< dL	< dL	< dL	< dL	< dL	< dL	0.563 ± 0.061	7.29 ± 0.15	22.94 ± 1.00
Mlambalala stream below	< dL	< dL	< dL	< dL	< dL	0.25 ± 0.02	< dL	0.558 ± 0.044	20.01 ± 0.01	20.18 ± 0.08
WET SEASON										
Blantyre Sewage Plant										

Raw	<dL	<dL	<dL	<dL	<dL	0.49 ± 0.02	0.014 ± 0.0	0.073 ± 0.0	11.51 ± 0.05	19.82 ± 1.25
Final	<dL	<dL	<dL	<dL	<dL	0.63 ± 0.03	<dL	0.116 ± 0.009	9.73 ± 0.50	18.65 ± 1.08
Mudi stream above	<dL	<dL	<dL	<dL	<dL	1.28 ± 0.20	0.033 ± 0.006	0.227 ± 0.025	9.89 ± 0.22	20.41 ± 1.25
Mudi stream below	<dL	<dL	<dL	<dL	<dL	1.69 ± 0.31	<dL	0.19 ± 0.01	9.90 ± 0.01	18.76 ± 0.92
Limbe Sewage plant										
Raw	<dL	<dL	<dL	<dL	<dL	0.1 ± 0.001	<dL	0.037 ± 0.008	11.13 ± 0.30	17.82 ± 1.91
Final	<dL	<dL	<dL	<dL	<dL	1.08 ± 0.19	<dL	<dL	11.04 ± 0.06	14.53 ± 3.08
Limbe stream above	<dL	<dL	<dL	<dL	<dL	3.07 ± 0.61	<dL	<dL	7.97 ± 0.03	10.41 ± 0.08
Limbe stream below	<dL	<dL	<dL	<dL	<dL	2.65 ± 0.041	<dL	<dL	7.16 ± 0.07	12.59 ± 3.16
Soche sewage plant										
Raw	<dL	<dL	<dL	<dL	<dL	0.297 ± 0.02	<dL	<dL	11.65 ± 0.50	10.75 ± 0.04
Final	<dL	<dL	<dL	<dL	<dL	0.072 ± 0.01	<dL	<dL	9.82 ± 1.08	11.35 ± 0.07
Mlambalala stream above	<dL	<dL	<dL	<dL	<dL	0.66 ± 0.10	<dL	<dL	22.00 ± 0.17	7.80 ± 0.09
Mlambalala stream below	<dL	<dL	<dL	<dL	<dL	0.873 ± 0.01	<dL	<dL	17.00 ± 1.58	9.02 ± 0.20

Appendix 9: Physical chemical characteristics of water in the streams of Blantyre city-

All parameters are in mg/l except for pH and otherwise specified

SAMPLING POINT	Cl ⁻	DO	BOD	COD	T	pH	Alkalinity	SS	O & G	EC mS	PO ₄ ³⁻	NO ₃ ⁻	SO ₄ ²⁻
DRY SEASON													
Limbe stream													
Mpingwe sports club	27.3 ± 0.2	3.3	13.01 ± 0.9	734.12 ± 0.9	26	8.6	420	2.01 ± 0.08	0.07 ± 0.005	9	0.83 ± 0.39	16.23 ± 0.31	7.12 ± 0.72
Highway bridge	30.2 ± 0.7	4.1	22.12 ± 0.1		28	8.3	450	25.30 ± 1.02		11	4.26 ± 1.16	139.94 ± 0.50	21.19 ± 1.79
Dalton bridge	32.7 ± 0.8	3	36.0 ± 1.0	1642.51 ± 26.7	27	7.9	430	6.00 ± 0.0	0.56 ± 0.009	12	3.61 ± 0.39	25.40 ± 3.57	14.58 ± 0.68
Naperi Stream													
Rainbow	49.7 ± 1.6	3.1	16.50 ± 2.10	402.0 ± 6.71	26	7.9	380	37.09 ± 0.98	0.02 ± 0.0	6	< dL	2.15 ± 0.55	21.88 ± 0.72
Moi road	30.2 ± 2	3.5	27.06 ± 3.0	623.65 ± 1.3	26.5	8	340	24.53 ± 1.09	0.78 ± 0.010	5	0.77 ± 0.0	138.87 ± 9.11	36.94 ± 0.96
Macro	32.7 ± 1.8	4.2	30.09 ± 0.8		27	7.8	320	38.02 ± 1.22		4	< dL	12.12 ± 1.2	34.72 ± 0.96
Kapeni	31.2 ± 4.1	4.1	16.60 ± 2.0		27	8	350	12.68 ± 0.98		4	< dL	67.97 ± 4.97	33.125 ± 0.0
Mudi stream													
M.D.I	33.4 ± 5.1	5.2	230.04 ± 4.2	316.01 ± 3.2	26	8.1	400	19.07 ± 1.05	0.57 ± 0.01	8	< dL	1.56 ± 0.01	83.83 ± 2.11
WICO	34.8 ± 3.2	4.5	180 ± 3.1		26	7.8	420	65.63 ± 3.05		4	2.82 ± 0.89	0.59 ± 0.27	17.45 ± 0.60
S.R.N	25.6 ± 0.9	4	270.44 ± 5.1	950.43 ± 10.3	26	7.3	380	32.05 ± 1.05	1.03 ± 0.01	5.5	4.62 ± 2.18	5.08 ± 0.40	11.70 ± 1.50
Clock Tower	36.9 ± 2.4	4.8	240 ± 3.4		26	7.1	540	25.67 ± 2.38		7	6.92 ± 1.09	7.23 ± 0.0	13.30 ± 0.15
Blantyre market	35.9 ± 0.5	4.6	180.82 ± 2.0		26	7.4	610	23.21 ± 1.23		5	2.69 ± 1.63	1.95 ± 0.17	13.09 ± 0.15
Victoria avenue	39.1 ± 1.5	4.1	300.5 ± 10.4		26	7.5	670	36.02 ± 0.45		8	2.56 ± 1.6	0.29 ± 0.14	8.62 ± 0.15
Nasolo stream													
BNC	83.4 ± 1.2	4.2	96.0 ± 1.2	778.0 ± 15.8	26.5	8.4	430	18.00 ± 0.63	0.07 ± 0.001	17	5.0 ± 0.0	111.25 ± 14.39	15.54 ± 0.43
S.R.N	53.3 ± 0.7	1	122.0 ± 5.4	691.56 ± 0.98	26	6.5	520	42.11 ± 0.53	2.46 ± 0.013	20	8.61 ± 1.18	8.37 ± 0.45	18.98 ± 1.22
Chirimba stream													
Behind Cori	22.7 ± 0.1	3.8	42.2 ± 0.3	821.0 ± 2.1	27	7.5	590	13.00 ± 0.56	0.164 ± 0.003	9	5.77 ± 1.63	243.07 ± 6.73	8.47 ± 0.32
Machinjiri road	25.3 ± 2.2	3	30.0 ± 2.0		27	7.2	420	39.78 ± 1.35	1.38 ± 0.04	20	10.26 ± 0.89	6.64 ± 1.55	103.61 ± 6.32
Zalewa road	36.7 ± 2.4	4	38.0 ± 1.1	864.01 ± 7.3	27	7.7	550	19.06 ± 0.98		17	19.2 ± 0.54	10.84 ± 2.35	116.77 ± 3.09
	Cl ⁻	DO	BOD	COD	T	pH	Alkalinity	SS	O & G	EC mS	PO ₄ ³⁻	NO ₃ ⁻	SO ₄ ²⁻

WET SEASON													
Limbe stream													
Mpingwe sports club	28.42 ± 0.09	2.5	11.08 ± 1.24	346.03 ± 17.01	25.1	7.7	220	42.99 ± 0.11	167.0 ± 8.4	3	0	33.31 ± 1.74	16.23 ± 2.46
Highway bridge	55.40 ± 0.0	1.4	51.0 ± 12.73	367.05 ± 10.02	25	7.2	280	7.00 ± 0.98		4.6	0	7.88 ± 0.92	23.04 ± 0.0
Dalton bridge	51.81 ± 0.01	1.2	54.03 ± 2.83	410.06 ± 0.91	24.7	7.2	210	3.02 ± 0.66	530.0 ± 13.4	4.6	0	32.95 ± 0.0	22.75 ± 1.02
Naperi Stream													
Rainbow	33.76 ± 0.06	1.4	16.5 ± 0.71	1015.05 ± 50.45	25.2	7.4	290	5.00 ± 0.0	0.17 ± 0.04	2.9	0	28.47 ± 4.50	5.36 ± 0.82
Moi road	31.90 ± 0.0	0.7	16.0 ± 2.83	389.04 ± 8.92	25.7	7	370	22.11 ± 2.01	0.06 ± 0.01	2.8	0	1.88 ± 0.41	7.97 ± 1.84
Macro	34.83 ± 0.13	2	4.51 ± 0.50	345.5 ± 54.44	25	7.5	280	27.00 ± 0.0		3	0	13.51 ± 3.17	7.46 ± 0.31
Kapeni		2.9	14.03 ± 1.41	302.00 ± 10.05	25	7.3	360	3.98 ± 0.02		2.8	0	49.64 ± 8.89	6.01 ± 1.54
Mudi stream													
M.D.I	26.66 ± 0.87	7	41.9 ± 3.26	324.98 ± 2.86	24.3	7.6	240	16.05 ± 0.54	0.73 ± 0.02	3.1	4.0 ± 0.81	16.91 v 0.0	10.00 ± 0.20
WICO	35.50 ± 0.01	2.1	39.0 ± 4.24	367.02 ± 4.23	25.2	7.4	300	40.01 ± 4.32		4.1	1.14 ± 0.81	2.6 ± 0.0	11.23 ± 0.10
S.R.N	32.70 ± 0.0	1	36.0 ± 0.0	346.04 ± 6.45	24.5	7.1	280	6.00 ± 0.76	2.29 ± 0.54	3.6	1.71 ± 0.81	2.75 ± 0.41	5.80 ± 0.0
Clock Tower	41.20 ± 0.0	0	26.50 ± 0.71	367.00 ± 0.76	25	7.7	450	14.20 ± 1.20		4.6	2.00 ± 0.40	1.73 ± 0.0	7.03 ± 0.72
Blantyre market	41.91 ± 1.02	1.4	11.0 ± 1.41	324.23 ± 7.71	24.5	7.8	390	38.00 ± 2.05		4.2	2.57 ± 0.40	0.15 ± 0.0	6.09 ± 0.41
Victoria avenue	37.60 ± 0.0	0.3	8.52 ± 0.66	346.01 ± 1.22	24.5	7.6	400	26.01 ± 1.10	0.11 ± 0.0	4.8	3.43 ± 0.81	0.87 ± 0.0	7.10 ± 0.62
Nasolo stream													
BNC	72.40 ± 0.0	3.2	35.0 ± 1.41	389.44 ± 5.46	24	8	410	26.00 ± 0.0	0.73 ± 0.03	6.2	0	37.57 ± 0.0	28.99 ± 1.64
S.R.N	53.61 ± 0.02	1	28.01 ± 2.83	310.00 ± 3.50	24.5	7.7	500	8.01 ± 0.38	0.67 ± 0.01	3.6	0	8.09 ± 0.0	13.04 ± 3.89
Chirimba stream													
Behind Cori	26.31 ± 0.06	2.9	70.5 ± 0.71	691.34 ± 12.24	25.2	7.1	390	46.00 ± 0.95	0.98 ± 0.07	3.5	0.29 ± 0.40	9.68 ± 0.0	19.56 ± 1.44
Machinjiri road	24.90 ± 0.10	1.7	12.60 ± 0.42	778.01 ± 7.01	25.2	6.9	380	283.78 ± 6.54	2.61 ± 0.85	4	1.43 ± 1.21	9.33 ± 1.34	36.16 ± 2.56
Zalewa road	44.72 ± 0.02	3.3	18.51 ± 0.70	790.21 ± 10.28	25	8.1	380	40.00 ± 2.21		5	5.43 ± 0.40	37.57 ± 0.0	37.10 ± 0.0

Appendix 10: Levels of metals in the streams of Blantyre city

All parameters are in mg/l

SAMPLING POINT	Cu	Ni	Cd	Cr	Pb	Fe	Zn	Mn	K	Ca
DRY SEASON										
Limbe stream										
Mpingwe sports club	0.048 ± 0.0	< dL	< dL	< dL	< dL	1.09 ± 0.03	< dL	< dL	7.70 ± 0.03	26.06 ± 0.08
Highway bridge	<dL	< dL	< dL	< dL	< dL	0.65 ± 0.02	1.02 ± 0.38	< dL	9.29 ± 0.28	24.71 ± 0.50
Dalton bridge	0.296 ± 0.011	< dL	< dL	< dL	< dL	< dL	< dL	< dL	11.55 ± 1.58	26.94 ± 0.0
Naperi Stream										
Rainbow	<dL	< dL	< dL	< dL	< dL	< dL	< dL	0.646 ± 0.021	19.93 ± 0.0	19.88 ± 0.17
Moi road	0.024 ± 0.011	< dL	< dL	< dL	< dL	< dL	< dL	0.472 ± 0.031	4.78 ± 0.01	18.82 ± 0.0
Macro	<dL	< dL	< dL	< dL	< dL	< dL	< dL	0.469 ± 0.002	6.18 ± 0.05	18.47 ± 0.83
Kapeni	<dL	< dL	< dL	< dL	< dL	< dL	< dL	0.327 ± 0.035	5.84 ± 0.05	20.76 ± 0.25
Mudi stream										
M.D.I	<dL	< dL	0.038 ± 0.009	< dL	< dL	< dL	< dL	0.464 ± 0.040	6.02 ± 0.08	39.41 ± 0.33
WICO	<dL	< dL	0.067 ± 0.003	< dL	< dL	< dL	0.11 ± 0.03	0.550 ± 0.004	10.52 ± 0.28	31.18 ± 0.17
S.R.N	<dL	0.222 ± 0.0	0.038 ± 0.001	< dL	< dL	< dL	0.082 ± 0.01	0.544 ± 0.016	6.21 ± 0.11	27.76 ± 0.0
Clock Tower	<dL	< dL	0.056 ± 0.005	< dL	< dL	0.72 ± 0.24	0.033 ± 0.006	0.546 ± 0.008	11.38 ± 0.12	33.18 ± 0.17
Blantyre market	<dL	0.222 ± 0.0	0.069 ± 0.004	< dL	< dL	0.71 ± 0.05	0.11 ± 0.05	0.378 ± 0.008	10.64 ± 0.47	29.35 ± 0.25
Victoria avenue	<dL	< dL	0.069 ± 0.007	< dL	< dL	1.58 ± 0.03	0.07 ± 0.02	0.244 ± 0.021	10.38 ± 0.06	29.41 ± 0.17
Nasolo stream										
BNC	<dL	< dL	< dL	< dL	< dL	1.54 ± 0.01	< dL	< dL	20.00 ± 0.0	40.12 ± 0.67
S.R.N	<dL	< dL	< dL	< dL	< dL	< dL	< dL	0.079 ± 0.028	20.00 ± 0.0	38.41 ± 0.25
Chirimba stream										
Behind Cori	<dL	< dL	< dL	< dL	< dL	< dL	< dL	0.605 ± 0.011	11.18 ± 1.56	25.12 ± 0.25
Machinjiri road	0.208 ± 0.0	< dL	< dL	< dL	< dL	< dL	1.21 ± 0.01	0.398 ± 0.009	20.01 ± 0.0	7.00 ± 0.08
Zalewa road	<dL	< dL	< dL	< dL	< dL	< dL	< dL	0.287 ± 0.011	8.44 ± 0.06	52.06 ± 1.08
WET SEASON										
Limbe stream										
Mpingwe sports club	0.068 ± 0.0	<dL	<dL	<dL	<dL	1.37 ± 0.02	<dL	<dL	5.11 ± 0.01	16.06 ± 0.92
Highway bridge	<dL	<dL	<dL	<dL	<dL	1.64 ± 0.03	<dL	<dL	7.82 ± 0.19	17.24 ± 0.08
Dalton bridge	<dL	<dL	<dL	<dL	<dL	1.57 ± 0.04	<dL	<dL	9.98 ± 0.03	24.35 ± 0.17
	Cu	Ni	Cd	Cr	Pb	Fe	Zn	Mn	K	Ca
Naperi Stream										
Rainbow	<dL	<dL	<dL	<dL	<dL	0.225 ± 0.08	<dL	<dL	5.50 ± 0.07	14.94 ± 0.67
Moi road	<dL	<dL	<dL	<dL	<dL	0.851 ± 0.06	<dL	0.169 ± 0.03	9.42 ± 0.17	12.94 ± 0.0

Macro	<dL	<dL	<dL	<dL	<dL	1.54 ± 0.26	<dL	0.114 ± 0.01	7.61 ± 0.20	12.18 ± 1.58
Kapeni	<dL	<dL	<dL	<dL	<dL	1.66 ± 0.14	<dL	<dL	7.19 ± 0.11	11.00 ± 0.08
Mudi stream										
M.D.I	<dL	<dL	<dL	<dL	<dL	2.06 ± 0.67	0.398 ± 0.0	0.398 ± 0.0	6.77 ± 0.03	12.29 ± 0.08
WICO	<dL	0.20 ± 0.01	<dL	<dL	<dL	1.71 ± 0.46	0.008 ± 0.0	0.465 ± 0.01	8.63 ± 0.44	21.41 ± 0.0
S.R.N	<dL	0.133 ± 0.021	<dL	<dL	<dL	1.24 ± 0.12	0.040 ± 0.01	0.492 ± 0.013	8.23 ± 0.87	21.94 ± 0.58
Clock Tower	<dL	0.235 ± 0.059	<dL	<dL	<dL	1.14 ± 0.44	<dL	0.396 ± 0.023	11.12 ± 0.20	24.88 ± 1.24
Blantyre market	<dL	0.241 ± 0.0	<dL	<dL	<dL	1.27 ± 0.30	<dL	0.579 ± 0.07	11.01 ± 0.26	28.00 ± 2.99
Victoria avenue	<dL	0.314 ± 0.079	<dL	<dL	<dL	1.32 ± 0.06	<dL	0.675 ± 0.011	11.30 ± 0.03	29.82 ± 0.08
Nasolo stream	<dL									
BNC	<dL	<dL	<dL	<dL	<dL	0.84 ± 0.28	<dL	<dL	13.17 ± 0.08	29.59 ± 1.58
S.R.N	<dL	<dL	<dL	<dL	<dL	0.84 ± 0.07	<dL	<dL	12.15 ± 0.03	23.41 ± 0.0
Chirimba stream	<dL									
Behind Cori	<dL	<dL	<dL	<dL	<dL	0.87 ± 0.02	<dL	0.136 ± 0.003	9.18 ± 0.13	16.12 ± 2.50
Machinjiri road	<dL	<dL	<dL	<dL	<dL	2.45 ± 0.20	<dL	0.183 ± 0.041	12.62 ± 0.01	14.88 ± 1.41
Zalewa road	<dL	<dL	<dL	<dL	<dL	1.06 ± 0.11	<dL	<dL	10.54 ± 0.38	24.47 ± 0.67

Appendix 11 : Test statistics

Appendix 11A- ONE WAY ANOVA

Parameter	Season	Groups	Sum of Squares	df	Mean squares	F	Sig
BOD	Dry	Between Groups	16417311	27	608048.545	37758.754	.000
		Within Groups	901.797	56	16.104		
		Total		83			
BOD	Wet	Between Groups	5390000	27	199629.613	330.871	.000
		Within Groups	33787.380	56	603.346		
		Total	5423787	83			
Cadmium	Dry	Between Groups	7.519×10^{-3}	11	6.836×10^{-4}	347.286	.000
		Within Groups	4.724×10^{-3}	24	1.968×10^{-6}		
		Total	7.567×10^{-3}	35			
Calcium	Dry	Between Groups	11847.030	15	789.802	4126.144	.000
		Within Groups	6.125	32	0.191		
		Total	11853.165	47			
Calcium	Wet	Between Groups	16594.314	15	1106.288	10023.227	.000
		Within Groups	3.552	32	0.110		
		Total	16597.846	47			
Chloride	Dry	Between Groups	206290	24	8595.417	2940.347	.000
		Within Groups	146.103	50	2.923		
		Total	206436.2	74			
Chloride	Wet	Between Groups	388308.5	27	14381.795	58086.541	.000
		Within Groups	13.865	56	0.248		
		Total	388322.3	83			
COD	Dry	Between Groups	3.4×10^9	27	126109717.1	3.839	.000
		Within Groups	1.84×10^9	56	32853594.82		
		Total	5.24×10^9	83			
Parameter	Season	Groups	Sum of Squares	df	Mean squares	F	Sig
COD	Wet	Between Groups	1.46×10^9	27	54003690.62	100976.5	.000
		Within Groups	29949.609	56	534.814		
		Total	1.46×10^9	83			
Copper	Dry	Between Groups	9.681	10	6.968	2413.138	.000
		Within Groups	8.826×10^{-3}	22	4.012×10^{-4}		
		Total	9.689	32			

Copper	Wet	Between Groups Within Groups Total	0.720 1.663 x 10 ⁻³ .722	7 16 23	0.103 1.039 x 10 ⁻⁴	990.093	.000
Iron	Dry	Between Groups Within Groups Total	68.958 0.559 69.517	14 15 29	4.926 3.726 x 10 ⁻²	132.207	.000
Iron	Wet	Between Groups Within Groups Total	716.2592 0.243 716.502	15 16 31	47.751 1.519 x 10 ⁻²	3144.079	.000
Lead	Dry	Between Groups Within Groups Total	13.930 0.212 14.142	5 12 17	2.786 1.764 x 10 ⁻²	157.90	.000
Manganese	Dry	Between Groups Within Groups Total	172.866 4.814 x 10 ⁻² 172.914	4 10 14	43.217 4.483 x 10 ⁻⁴	8976.512	.000
Parameter	Season	Groups	Sum of Squares	df	Mean squares	F	Sig
Manganese	Wet	Between Groups Within Groups Total	2.815 6.276 x 10 ⁻⁴ 2.821	6 14 20	0.469 4.483 x 10 ⁻⁴	1046.598	.000
Nickel	Dry	Between Groups Within Groups Total	1.578 4.805 x 10 ⁻² 1.626	2 6 8	0.789 8.009 x 10 ⁻³	98.533	.000
Nitrates	Dry	Between Groups Within Groups Total	162265.7 6747.548 169013.3	27 56 83	6009.842 120.492	49.878	.000
Nitrates	Wet	Between Groups Within Groups Total	10109.855 36.189 10146.044	27 56 83	374.439 0.646	579.418	.000
Phosphates	Dry	Between Groups Within Groups Total	2663106 657.301 2663763	27 56 83	98633.544 11.738	8403.269	.000
Phosphates	Wet	Between Groups Within Groups Total	136722.6 124.017 136846.6	27 56 83	5063.800	2286.555	.000
Sulphates	Dry	Between Groups Within Groups Total	590280.8 683.136 590964.0	27 56 83	21862.252 12.199	1792.156	.000
Parameter	Season	Groups	Sum of Squares	df	Mean squares	F	Sig
Sulphates	Wet	Between Groups	12151161	27	450042.988	6154.04	.000

		Within Groups Total	4095.262 12155256	56 83	73.130		
Suspended Solids	Dry	Between Groups Within Groups Total	16.93 x 10 ⁷ 4042.584 16.93 x 10 ⁷	27 56 83	2567322 72.189	35564.00	.000
Suspended solids	Wet	Between Groups Within Groups Total	8.262 x 10 ¹⁰ 4.51 x 10 ⁶	27 56 83	3.06 x 10 ⁹ 80557.961	371227.9	.000
Potassium	Dry	Between Groups Within Groups Total	1606.021 .664 1606.684	15 12 47	107.068 2.075 x 10 ⁻²	5160.799	.000
Potassium	Wet	Between Groups Within Groups Total	843.220 9.675 x 10 ⁻³ 843.317	15 32 47	56.215 3.023 x 10 ⁻³	18592.969	.000
Zinc	Dry	Between Groups Within Groups Total	1927.217 0.174 1927.392	27 56 83	71.378 0.003	22916.939	.000
Zinc	Wet	Between Groups Within Groups Total	3303.555 10.650 3314.204	27 56 83	122.354 0.190	643.378	.000

Appendix 11B: Independent t test

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	F	Sig	t	df	Sig (2 -tailed)	Mean Difference	Std. Error Difference	95% CI of the difference	
								Lower	Upper
Chromium (wet season)	0.891	0.382	-58.790	6	0.00	-14.5300	.2472	-15.1348	-13.9252
Equal var assumed			-58.790	3.984	0.00	-14.5300	.2472	-15.2173	-13.8427
Lead (wet season)	2.629	.149	418.716	7	.000	2327750	.0005559	.2314604	.2340896
Equal var assumed			450.240	6.208	.000	2327750	.0005170	.2315201	.2340299
Equal var not assumed									

Independent t test between seasons for various variables									
Nitrate									
Equal var assumed	32.025	0.000	3.355	166	0.001	17.00911	5.06922	7.00066	27.01756
Equal var not assumed			3.355	92.927	0.001	17.00911	5.06922	6.94254	27.07567
Chloride									
Equal var assumed	0.300	0.585	-1.391	166	0.166	-12.98254	9.330344	-31.4040	5.4389019
Equal var not assumed			-1.391	153.965	0.166	-12.98254	9.330344	-31.4146	5.4494813
Sulphates									
Equal Var assumed	7.766	0.006	-1.513	166	0.132	-64.69244	42.757471	-149.111	19.72611
Equal Var not assumed			-1.513	91.052	0.134	-64.69244	42.757471	-149.624	20.23938
Phosphates									
Equal Var assumed	15.603	0.000	2.127	166	0.035	42.632744	20.042302	3.062069	82.20342
Equal Var not assumed			2.127	91.506	0.036	42.632744	20.042302	2.824137	82.44135
BOD									
Equal Var assumed	38.962	0.000	2.316	166	0.022	129.64393	55.971572	19.13602	240.1818
Equal Var not assumed			2.316	132.443	0.022	129.64393	55.971572	18.93005	240.3578
COD									
Equal Var assumed	2.830	0.094	0.794	166	0.428	778.29464	980.51098	-1157.58	2714.174
Equal Var not assumed			0.794	125.840	0.429	778.29464	980.51098	-1162.13	2718.721
DO									
Equal Var assumed	2.993	0.086	-0.887	166	0.376	-0.2237226	0.2521913	-7216384	0.2741932
Equal Var not assumed			-0.887	141.430	0.377	-0.2237226	0.2521913	-722744	0.2748291
Oil & Grease									
Equal Var assumed	2.432	0.121	0.565	166	0.573	7.9649226	14.108224	-19.8898	35.81960
Equal Var not assumed			0.565	106.069	0.574	7.9649226	14.108224	-20.0058	35.93564
PH									
Equal Var assumed	0.678	0.412	1.041	166	0.299	0.26667	0.25619	-0.23915	0.77248
Equal Var not assumed			1.041	163.606	0.299	0.26667	0.25619	-0.23920	0.77254
Alkalinity									
Equal Var assumed	3.946	0.049	2.406	166	0.017	212.56524	88.36095	38.10911	387.02136
Equal Var not assumed			2.406	163.110		212.56524	88.36095	38.08641	387.04407

APPENDIX 11C - CORRELATION

Parameter	Pearson Correlation	Sig.	Correlation Notes
DO & COD (Wet)	0.080	0.469	
BOD & COD (Wet)	0.481	0.000	Correlation significant at 0.01 level
DO & COD (Dry)	-0.057	0.604	
BOD & COD (Dry)	.240	0.028	Correlation significant at 0.05 level (2-tailed)
DO & BOD (Wet)	-0.131	0.234	
BOD & DO (Dry)	-0.312	0.004	Correlation significant at 0.01 level
Alk & PH (Dry)	0.721	0.000	Correlation significant at 0.01 level (2-tailed)
Alk & PH (Wet)	0.750	0.000	Correlation significant at 0.01 level (2-tailed)
OG & DO (Dry)	-0.167	0.129	
OG & DO (Wet)	-0.082	0.459	

Appendix 11D :Mannwhitney test

Parameter	Season	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig(2-tailed)	Exact Sig[2* (1-tailed. Sig)].
Chromium	Wet	0.00	10.00	-2.337	0.019	0.029
Lead	Wet	0.00	15.00	-2.481	0.013	0.016
Nickel	Wet	0.00	10.00	-2.337	0.019	0.029