LEVELS OF SELECTED HEAVY METALS AND RELATED PHYSICO - CHEMICAL PARAMETERS OF ALGAE (*Spirogyra aequinoctialis*), EARTHWORMS (*Aporrectodea icteria*), SOIL AND WATER IN BLANTYRE CITY, MALAWI

MSc. (ENVIRONMENTAL SCIENCES) THESIS

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Thesis submitted to the Faculty of Science in Partial Fulfillment of the Requirements for the Degree of Master of Science in Environmental Sciences, at Chancellor College, University of Malawi, Zomba

May, 2007

DECLARATION

I declare that this work is a result of my own effort and that it has not been presented or submitted elsewhere for any award. All additional sources of information used have been acknowledged.

Signature……..Date……...
Chikumbusko Chiziwa Kaonga

We hereby declare that this 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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Signature……..Date……...
Prof. S.S. Chiotha (Supervisor and Coordinator, Masters in Environmental Science Program)

DEDICATION

To my wife Annie, who stood by me despite the challenges that we had to face.

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ABSTRACT

This study assessed the ability of filamentous green algae (*Spirogyra aequinoctialis*) and earthworms (*Aporrectodea icteria*) to accumulate heavy metals from water and soils, respectively. Samples of *S. aequinoctialis,* A. *icteria* and their respective water and soil environments were taken from designated sampling points in the City of Blantyre in Malawi during the rainy and dry season in order to capture seasonal variations. The samples were analyzed for pH, organic matter and the heavy metals cadmium, chromium, copper, iron, lead, nickel and zinc using standard methods (APHA, AOAC and Walkley - Black). The concentrations of metals in soils, algae and earthworms were on dry weight basis and the metals determined were acid extractable.

In general, the concentration of metals in *S. aequinoctialis* were higher than in the corresponding water environment in both seasons, but lower in the rainy season than the dry season. In the rainy season the concentrations were (in *S. aequinoctialis* and (water)): Mn 0.432 - 5.641 mg/L (ND - 0.530 mg/L), Cd ND - 0.016 mg/L (0.07 - 0.111 mg/L), Cu 0.002 - 0.826 mg/L (ND), Fe 30.75 - 81.36 mg/L (ND - 3.209 mg/L), Zn 0.202 - 3.270 mg/L (0.502 - 2.614 mg/L), Pb ND - 0.965 mg/L (0.011 - 0.098 mg/L), Cr ND – 0.431 mg/L (ND) and Ni ND - 0.443 mg/L (0.305 - 0.49 mg/L). In the dry season the concentrations were: Mn 0.281 - 16.132 mg/L (0.035 - 0.626 mg/L), Cd 0.22 - 0.912 mg/L (0.014 - 0.111 mg/L), Cu 0.056 - 2.302 mg/L (ND - 0.076 mg/L), Fe 13.825 - 96.641 mg/L (0.372 - 2.282 mg/L), Zn 0.203 - 6.188 mg/L (0.102 - 0.403 mg/L), Pb ND - 0.972 mg/L (ND - 0.23 mg/L), Cr ND - 0.663 mg/L (ND - 0.419 mg/L) and Ni ND - 0.421 mg/L (0.101 - 0.578 mg/L).

The concentration of metals in soils was found to be higher than in *A. icteria*, except for cadmium. In both soils and *A. icteria* the levels of metals were generally higher in the dry season than the rainy season. In the rainy season the concentrations were (in *A. icteria* and (soil)): Mn 1.005 - 9.623 mg/kg (10.255 - 17.894 mg/kg), Cd 0.108 - 0.144 mg/kg (ND - 0.041 mg/kg), Cu ND - 0.413 mg/kg (ND - 0.041 mg/kg), Fe 14.67 - 54.82 mg/kg (61.283 - 67.560 mg/kg), Zn 0.664 - 5.274 mg/kg (1.372 - 17.45 mg/kg), Pb ND - 0.796 mg/kg (0.512 - 2.945 mg/kg), Cr ND (ND - 6.832 mg/kg) and Ni 0.291 - 0.869 mg/kg

(ND - 2.891 mg/kg). In the dry season the concentrations were: Mn 1.603 - 7.582 mg/kg (8.995 - 31.43 mg/kg), Cd 0.155 - 0.551 mg/kg (ND - 0.179 mg/kg), Cu 0.005 - 0.916 mg/kg (0.119 - 10.134 mg/kg), Fe 13.697 - 63.727 mg/kg (11.827 - 82.824 mg/kg), Zn 0.461 - 5.109 mg/kg (0.255 - 14.463 mg/kg), Pb ND - 0.476 mg/kg (0.031 - 3.485 mg/kg), Cr ND - 0.031 mg/kg (0.053 - 8.191 mg/kg) and Ni 0.043 - 0.93 mg/kg (0.026 - 4.319 mg/kg).

There were no significant differences ($p > 0.05$) in organic matter content in soils for rainy (0.588 - 9.266%) and dry season (0.559 - 9.357%). There were also no significant differences ($p > 0.05$) in water pH for rainy (5.99 - 10.13) and dry season (5.98 - 9.68). However, there were significant differences ($p < 0.05$) in soil pH between the rainy (6.47 - 8.37) and the dry season (6.27 - 7.75).

This study has therefore shown that *S. aequinoctialis* has the capability of accumulating Mn, Cd, Cu, Fe, Zn, Pb and Cr and can be used as a biological indicator for long term metal water pollution monitoring. However *A. icteria* showed the ability to accumulate Cd only and therefore cannot be used as a biological indicator for metal soil pollution monitoring. The high concentration of metals in the dry season unlike the rainy season was mainly attributed to dilution and soil deposition as a result of surface runoff.

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ACRONYMS

AAS	Atomic Absorption Spectrophotometer
AOAC	Association of Official Analytical Chemists
APHA	American Public Health Association
AR	Analytical Reagent
BCA	Blantyre City Assembly
BNC	Blantyre Netting Company
BRS	Bvumbwe Research Station
CORI	Capital Oil Refineries Limited
CWT	Cornwall Wildlife Trust
DEAP	District Environmental Action Plan
DDT	Dichloro Diphenyl Tetrachloro - ethane
EPA	Extension Planning Area
FAO	Food and Agriculture Organization
GEF	Global Environment Fund
GoM	Government of Malawi
GoM-SEP	Government of Malawi- Social Economic Profile
GPR	General Purpose Reagent
GPS	Geographical Positioning System
IHE	Infrastructure Hydraulics Environment
ISWS	Illinois State Water Survey
MDI	Malawi Dairy Industries
MDA	Minnesota Department of Agriculture
ND	Not Detected
NEAP	National Environmental Action Plan
NSW	New South Wales
PIC	Prior Informed Consent
POPs	Persistent Organic Pesticides
RDP	Rural Development Project
SADC	Southern African Development Community
SDF	Southern Division Fired

SOER	State of Environment Report
SPSS	Statistical Package for the Social Sciences
SRN	S.R Nicholas
SA-WRC	South African Water Resource Commission
SWFWMD	South West Florida Water Management District
SWRCB	State Water Resources Control Board
UEMP	Urban Environmental Management Project
UN	United Nations
UNCHS	United Nations Center for Human Settlement
UNCTAD	United Nations Conference on Trade and Development
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNSO	United Nations Sudano-Sahelian Office
US-EPA	United States Environmental Protection Agency
US-FWS	United States Fish and Wildlife Service
USOER	Urban State of Environment Report
WHO	World Health Organization
WRB	Water Resources Board
WWTP	Waste Water Treatment Plant

CHAPTER 1

1.0 INTRODUCTION AND LITERATURE REVIEW

1.1 Background

Environmental degradation is a widely recognized global challenge. Some of the problems now affecting the world are acid rain, global warming, hazardous wastes, ozone depletion, smog, water pollution, overpopulation and rain forest destruction (ThinkQuest, 1999; Gibbons, 2006). Environmental problems common in the SADC region are deforestation, desertification, degradation of coastal areas, over fishing, loss of wildlife and other biodiversity resources, land degradation, the dumping by other countries of wastes, environmentally harmful products and obsolete technologies (UNCTAD, 1999). In Malawi the major environmental problems are ranked in the order; soil erosion, deforestation, water resources degradation and depletion, threat to fish resources, threat to biodiversity, human habitat degradation, high population growth, air pollution and climatic change (GoM, 1994).

Environmental pollution is one of the major causes of environmental degradation worldwide. Holdgate (1979) defines pollution as the introduction by man into the environment of substances or energy liable to cause hazards to human health, harm to living resources and ecological systems, damage to structures or amenity, or interference with legitimate uses of the environment. Although pollution of our environment has occurred for centuries it has only become a significant problem within the last few decades due to increase in population and scientific understanding (Moriarty, 1975). The simple nature and relatively small volume that characterized wastes in the past have since been changing with the advent of urbanization and industrialization (Sangodoyin and Ipadeola, 2000; Rao, 2004).

The physical and chemical effects of pollution can, from an ecological point of view, be divided into five categories, which are addition of poisonous substances, addition of suspended solids, de-oxygenation, addition of non-toxic salts and heating of water (Hynes, 1974). The two main biological effects of pollution are first the simple elimination of certain species often accompanied by a corresponding increase of those that remain, a result of purely man-made types of pollution. The second is the

replacement of the normal community by another, which becomes adjusted to the changed ecological conditions (Hindle, 1959). Organisms acquire toxic substances from the environment along with nutrients and water. Some of the poisons are metabolized and excreted, but others accumulate in specific tissues. This capacity is widely recognized as offering one way of monitoring the distribution of toxins in the environment. One of the reasons these toxins are so harmful is that they become more concentrated in successive trophic levels of a food web, a process called biological magnification (Campbell, 1996; Woodwell, 1972).

Monitoring the distribution of toxins in the environment is important because it provides data required for planning, it helps in the determination of the health and condition of a particular environment, it provides a means to record environmental changes and trends over time and it helps in focusing conservation efforts by relevant authorities towards decision making (Roth et al., 1997; SWFWMD, 2006; Cotching, 2006). The use of living organisms to monitor the distribution of toxins in the environment is called biological monitoring while the organisms are called biological indicators.

1.2 Biological monitoring

Most organisms are sensitive to changes in their environment whether it is natural (turbidity during floods) or unnatural such as pollution. In a few cases the response may be extreme such as death or migration of organisms. Less obvious and far more common responses include a decrease in the reproductive capacity and a decrease in normal metabolic rate as a result of inhibition or stimulation of certain enzymes. Once these responses have been identified in particular organisms they may be used to determine the quality of the environment (Chapman, 1996). The state of the environment in terms of pollutant load can be monitored by conducting biological assessments. There are six main approaches of conducting biological assessments, which are:

i. *Ecological methods*: This looks at presence or absence of indicator species, analysis of biological communities (biocenosis) and analysis of biocenosis on artificial substrates.
ii. *Microbiological methods*: This involves detecting the presence of bacteria or pathogens to minimize health risks.

iii. *Physiological and biochemical methods (Biomarkers)*: Tests in this study include oxygen production, consumption and respiration changes as a result of contaminants. Other tests include measuring the sugar and glycol levels in the blood and tissue of organisms to find out the levels of stress. However very few tests are suitable for routine monitoring and assessment as they can be complex and expensive to perform.

iv. *Bioassay and toxicity testing*: In this case, organisms are exposed to different contaminants in varying concentrations in order to obtain a response (Chapman, 1996). This is usually a very specialist approach requiring a high level of expertise and equipment.

v. *Chemical analysis of biota (Bioaccumulation)*: In this case studies are concerned with the trophic dynamics of chemicals e.g. study of the 'food chain transfer' when an organism which has accumulated a contaminant such as DDT is eaten by another organism which in turn accumulates the contaminant from the tissues of its food source and ends up with a concentration of the contaminant that is in far higher concentrations than would be occurring in the environment.

vi. *Histological and morphological methods*: The presence of pollutants has been shown to cause genetic variability within populations (Bunn, 1995). Examples of these are histological and morphological changes such as tumours and deformities. These are usually used for research or special surveys. The reason being that it is not normally possible to stimulate the exact environmental conditions i.e. amount and frequency of a particular pollutant or a number of factors may be causing the changes in the organism. As a result, the results obtained in a laboratory may not reflect what is happening in the field.

In Malawi attempts have been made on biological monitoring. Kachale (2000) looked at the development of a biomonitoring system for water quality management in Malawi. In his study he suggested the use of benthic macroinvertebrates as the most cost-effective technique that can be used to identify the general health conditions of rivers in Malawi by virtue of their worldwide acceptance as indicators of water quality. At Blantyre Waste water treatment plant, Blantyre City Assembly rears sheep which act as indicators of pollution. These sheep graze on the lawn inside the waste water treatment plant and drink

water from the oxidation ponds. These sheep are used to monitor general pollution and not a specific pollutant (Figure 1.1).

Figure 1.1: Sheep that are used as indicators of general pollution at Blantyre Wastewater Treatment Plant

1.2.1 Biological indicators

An indicator is a sign or signal that relays a complex message, potentially from numerous sources, in a simplified and useful manner. The primary uses of an indicator are to characterize current status and to track or predict significant change. Biological indicators are used because they integrate, in themselves, the effects of various stressors. Indicator organisms reflect current conditions, as well as changes over time and cumulative effects. Biological indicators can show problems otherwise missed or underestimated. The most usual animal bioindicators are invertebrates and vertebrates such as fish, mammals and less frequently birds (Loumbourdis, 1996; US-EPA, 2005; Gramatica1 et.al, 2006; Barnes, 1998).

The use of plants and animals as indicators of environmental stability is widely recognized. An obvious advantage of using bioindicators is that these show the results of the action of particular pollutants on living material-a relevant, if at times rather emotive, approach to determining human technological impact on the biosphere. It will never be

possible to replace direct physical and chemical measurements of pollutant concentrations entirely by the use of bioindicators because the later are useful for cross checking or filling in gaps in the data; nevertheless, both approaches are necessary for making a detailed or large-scale survey of the distribution of pollutants (Seaward, 1994; Blanusa, 1996; Nirel and Revaclier, 2003; Klein, 1966; FAO, 1999).

In soils and water heavily contaminated by chemicals or wastes, there is a decrease in the population, growth and function of biota. The identification of plant and animal species with the ability to accumulate selected chemical elements is of interest for the purposes of environmental biomonitoring, especially as it relates to the monitoring of soil and water composition (Chukwuma, 1998; Manly, 1996).

1.2.2 Indicator species

Although there are a number of organisms that can be used as indicators, invertebrates and periphyton are easy to use. Invertebrates are easy to collect, easy to identify in a laboratory, often live for more than one year, have limited mobility and are integrators of environmental condition. Examples of invertebrates commonly used as indicators are earthworms, midges and stoneflies. Periphyton are used because there is a naturally high number of species, they offer a rapid response time to both exposure and recovery, identification to a species level by experienced biologists is possible, ease of sampling, tolerance or sensitivity to specific changes in environmental condition are known for many species (US-EPA, 2005; Zaborski, 1998).

1.2.2.1 Earthworms

Earthworms belong to a group of invertebrates known as annelids and are known to be pollution resistant. Of the more than two hundred species known, *Lumbricus terrestris* a reddish organism and *Allolobophora caliginosa*, pale pink in color are the two most common in Europe and eastern and central United States. In the tropics and semi-tropics still other types are prevalent, some small and others surprisingly large with those originating from Africa belonging to the families Almidae, Acanthodrilidae, Ocnerodrilidae and Glossoscolecidae (Brady and Weil, 1999; Russell, 1961; Wikipedia, 2006).

Earthworms thrive where farm manure or plant residues have been added to the soil. A few species are reasonably tolerant to low soil pH but most earthworms thrive best where the soil is not too acid (Russell 1961; Brady, 1974).

As soil-dwelling animals, earthworms form a major link in the chain of bioaccumulation of pesticide and heavy metal residues. They are able to store relatively high concentrations of pesticides and heavy metals in their bodies, in some cases up to ten times the concentration found in soil, and they pass these compounds right along to their predators (Worm world, 2005; Standiford et al., 2000).

1.2.2.2 Periphyton

Periphyton are benthic algae that grow attached to surfaces such as rocks or larger plants. This assemblage makes them to easily integrate physical and chemical disturbances of the stream. They usually require hard substrates, but some species are able to grow on soft bottoms forming meadows, an example include those of the genera *Caulerpa* and *Penicillus*. Periphyton are primary producers and sensitive indicators of environmental change in lotic waters (US-EPA, 2005). In addition to the uptake of nutrients, algae can also take up toxic compounds such as heavy metals (Page et al., 2006, Donnan, 2006; White and Broadley, 2003). Periphyton reflect the concentration of heavy metals present in the environment and are considered good biomonitors of these contaminants (Sanchiz et al., 2000; Johansson et al., 1994). Heavy metal tolerance has been demonstrated for green algae like *Chlorella* and *Scenedesmus* (Pinto et al., 2003), which is the most diverse group of algae, with more than 7000 species growing in a variety of habitats (Speer, 1998).

1.3 Water pollution

Water pollution is any human-caused contamination of water that reduces its usefulness to humans and other organisms in nature (US - EPA, 1997). Rivers and streams are among the most degraded ecosystems. The majority of rivers of the world have been modified by human activities, which is widely recognized as the cause of global-scale habitat loss and degradation in the lotic environment (Nakano and Nakamura, 2006; Arnold & Beristain, 1993). The polluting industries are located near water sources for three very cogent reasons: the manufacturing plants use lots of water, they must have a

place to dispose of the dirty water (a very large percentage) and they can often save money by delivering their products by barge rather than by truck or railroad (Carr, 1966).

A modern city of one million people could require as much as 500 megalitres per day of potable water to meet its needs and as much as 90% of this would have to be dealt with as effluent which may contain human wastes, detergents, oils and fats depending on the degree of development of the area. Industrial wastes, on the other hand, may contain a vast array of materials like fertilizers, herbicides, insecticides, fungicides, acids, oils and other synthetic chemicals. Nearly all of these effluents have to be discharged to a water body (some are recycled by industry) and unless they are monitored and controlled chaos may result, as often one person's effluent is another person's drinking water (Oyebande, 1975; Barrow, 1987; James, 1978). Basically there are four different types of water pollution which are natural pollution, thermal pollution, sewage pollution and industrial pollution (Aylesworth, 1968). Except for thermal pollution, the three remaining types of water pollution may directly introduce heavy metals into water bodies.

The main sources of pollutants for water bodies in Malawi are contaminated industrial effluents, wastewater/sewage treatment plants and agricultural practices. Studies done in Malawi have confirmed pollution by heavy metals in water bodies. Sajidu et al. (2006) found that the levels of lead, cadmium, iron, manganese, zinc, chromium and nickel in streams in the city of Blantyre to be much higher than WHO safe limits for drinking water in all sampled streams after they had passed through industrial areas. Lakudzala et al. (1999) found that at some points on Mudi, Likhubula and Shire rivers, the iron and lead levels exceeded WHO guideline limits. Msonda (2003) carried out studies in Nathenje, Lilongwe and found that 24% of the boreholes had iron levels above WHO maximum acceptable limits in the rainy season and 22% in the dry season, 2% of the boreholes had lead concentration above WHO maximum permissible limit in the rainy season and 3% in the dry season, 6% of the boreholes had manganese levels above WHO maximum permissible limits in both the rainy season and the dry season. Nyirongo (2003) found that chromium, lead, cadmium and manganese levels in the rainy season exceeded maximum permissible limits of WHO, MBS and WRB in water and effluent from Limphasa rice scheme. Kwanjana (2003) found that the concentration of manganese and cadmium were higher than the acceptable limits for irrigation water set by FAO for

Zomba municipal sewage effluent. Zembere et al. (1999) found high levels of chromium than the maximum permissible levels by WHO at Mangunda stream, Blantyre.

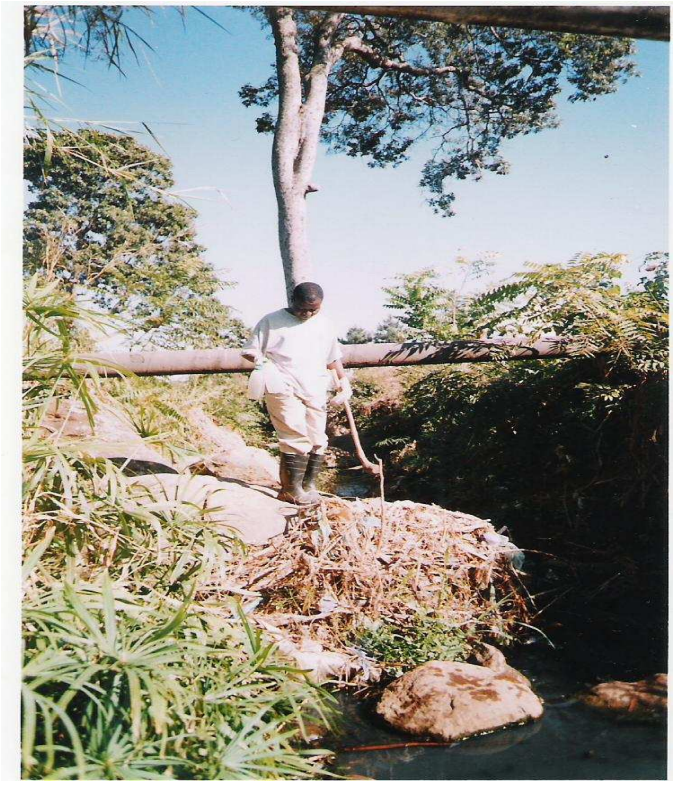


Figure 1.2: A sewer pipe passing over Naperi stream whereby blockages lead to sewage pollution. Residential wastes can be seen collecting on the rocks

1.4 Soil pollution

Soil pollution is the introduction of substances, biological organisms or energy into the soil, resulting in a change of the soil quality, which is likely to affect the normal use of the soil or endangering public health and the living environment (US - EPA, 2000). Soils not only serve as sources of certain metals but also function as sinks for metal contaminants. Soil pollution damages the thin layer of fertile soil that covers much of the earth's land and is essential for growing crops, vegetables and fruits (Syed, 2006). There are various means of soil pollution with the major ones being overburdens of mines, industrial effluents, domestic waste, fertilizers and pesticides application. Heavy metal contamination in soils is influenced by a number of factors, including agriculture. This is usually a result of impurities in the fertilizers and crop residues, could also be caused by

sewage irrigation, parent materials or airborne particulate transport. Heavy metal contamination in soils is also effected by pH and soil organic matter content (ThinkQuest, 2001; Sahu et al, 2004; Li et al., 2006; Nicholson et al., 2006). Soil contaminated by trace metals has been given more attention in recent years, for example arsenic, cadmium, lead and zinc contaminating agricultural soils in Belgium have been estimated to average 16, 20, 260 and 3,800g per hectare per year, respectively. Similarly, about 9.5 per cent of rice paddy soil in Japan has been declared unsuitable for growing rice for human consumption because of high metal contamination (Asami, 1983; Navarre et.al, 1980).

In Malawi the main sources of soil pollution are waste disposal, industrial effluents and agricultural practices. Studies done in Malawi have confirmed the presence of heavy metals in soils. For example, Kadewa (2001) found levels of copper, cadmium and chromium in soils fertilized by sewage sludge from Soche waste water treatment plant, Blantyre to be higher than the range for critical concentration for sludge amended soils. One of the important soil factors that influence availability of organisms like earthworms and presence of heavy metals is soil organic matter.

1.4.1 Soil organic matter

Soil organic matter represents an accumulation of partially decayed and partially synthesized plant and animal residues. Microbes (mainly fungi and bacteria) are the most important for decomposition, whereas the soil fauna (such as earthworms, mites, crustaceans and centipedes) determine the amount and composition of the microbial community through its predatory action. The organic matter content of a soil is small, only about 3 to 5 percent by weight, in a representative mineral topsoil. However its influence on soil properties and consequently on plant growth is far greater than the low percentage would suggest. Apart from its effect on the physical condition of soils, organic matter also increases the amounts of water a soil can hold and the proportion of water available for plant growth. Soil organic matter consists of two general groups:

a) Original tissue and its partially decomposed equivalents
b) Humus

The original tissue includes the undecomposed roots and the types of higher plants. The more resistant gelatinous products of this decomposition, both those synthesized by the micro-organisms and those modified from the original plant tissue, are collectively

known as humus. This material, usually black or brown in colour, is colloidal in nature. Its capacity to hold water and nutrient ions greatly exceeds that of clay, its inorganic counterpart. Metals are strongly adsorbed by the soil clay and humus and, therefore, do not leach to any extent (Davies et al., 1972; Brady, 1974; Gustafsson et al., 2005; Knowles & Watkin, 1960).

1.5 Heavy metals

'Heavy metals' is a general collective term applying to the group of metals and metalloids with an atomic density greater than 6g/cm^3. Although it is only a loosely defined term, it is widely recognized and usually applied to the elements such as cadmium, chromium, copper, mercury, nickel, lead and zinc, which are commonly associated with pollution toxicity problems. An alternative (and theoretically more acceptable) name for this group of elements is 'trace metals' but it is not as widely used (Alloway and Ayres, 1997). The problem of exposure to heavy metals and their biological effects has been a source of growing concern in many countries (Piasek and Kostial, 1996). Some heavy metals (e.g. cadmium and arsenic) are exclusively toxic to biological systems and classified as being non-essential. Others (e.g. zinc and copper) are essential for life. Their toxicity is linked to their mobility in soil, whereby the greater the mobility, the higher the toxicity risk. Heavy metal mobility mainly depends on soil properties. One important process affecting heavy metal mobility in soil is sorption (Gunkel et al., 2003; Antoniadis and McKinley, 2003; Worm world, 2005; El-Shafai et.al, 2006). The pH is the most important parameter that governs the adsorption of inorganic ions. One reason is that a large part of the particle charge is variable, and therefore electrostatic attraction is different depending on the pH value. Hence anions are adsorbed more strongly at low pH (when the oxides contain many positively charged groups) whereas cations are more strongly sorbed at high pH (because humic substances and oxides become more negatively charged) (Gustafsson et.al, 2005; Penney, 2004; Iretskaya and Chien, 1999).

Heavy metals are conservative pollutants in that they are not broken down over along time scale such that they effectively become permanent additions to the environment. They accumulate in organisms and some may biomagnify in food chains (Cho et al.,

2003; Mason, 1991; Lide, 1998). Chiotha (1992) reported the possibility of fish accumulating heavy metals like mercury by eating certain types of algae.

Pollution gives rise to anomalously high concentrations of heavy metals than the normal background levels. Therefore presence of the metal is insufficient evidence of pollution, the relative concentration is all that is important. The major sources of heavy metals include; geochemical sources where heavy metals occur as 'impurities' isomorphously substituted for various macroelement constituents of the crystal lattice of many primary minerals and anthropogenic sources which include metalliferous mining, agricultural minerals, fossil fuel combustion, metallurgical industries, electronics and waste disposal (Alloway and Ayres, 1997).

In Malawi pollution by heavy metals has been shown in other media apart from water and soils. Henry and Kalua (2001) found high lead concentrations in an MBS certified edible oil and other four generic commercial edible oils in Zomba.

1.6 Problem statement

Studies done elsewhere have shown that many living organisms accumulate pollutants within their tissues (bioaccumulation) and thus may be used in pollution surveillance programmes. Many pollutants may be present in water, air and soil at levels below or close to the detection limits of many chemical analytical methods. In contrast, tissues that have accumulated pollutants exhibit levels of pollutants often well within typical analytical detection limits. Also, the analysis of discrete samples of air, water and soil provide only a record of the levels of pollutant present at the time they were taken, whereas those observed in a bioaccumulator organism will reflect the ambient levels present over a prolonged period of time (Manly, 1996; Mason, 1996).

The recent government policy is to change Malawi from a consuming nation to a producing nation. This will involve increase in agricultural production and industrial development (GoM, 2005). This means that as industrial and agricultural activities increase, pollution by heavy metals will likely increase. Studies have already shown heavy metal pollution (Sajidu et al. (2006), Lakudzala et al. (1999), Nyirongo (2003), Henry and Kalua (2001), Kwanjana (2003), Zembere et al. (1999) and Kadewa (2001)).

These studies however have not looked at the development of a monitoring system (As proposed by Environmental Long-Term Observatories of Southern Africa (ELTOSA) - a network of Southern African countries embarking on time-series environmental research and monitoring programmes delivering time-series datasets) for heavy metals in Malawi hence the need for this study which looked at pollution in biota (earthworms (*Aporrectodea icteria*) and algae (*Spirogyra aequinoctialis*)), since these provide an opportunity to monitor pollution that may be missed in the analysis of water and soils.

1.7 General objective of the study

The general objective of the study was to assess the possibility of using biota in the monitoring of pollutants in soils and water resources of Malawi.

1.8 Specific objectives

a) To determine the levels of chromium, manganese, lead, copper, zinc, nickel, cadmium and iron in algae (*S. aequinoctialis*), water, soil and earthworms (*A. icteria*) in the dry and the rainy season
b) To compare the levels of chromium, manganese, lead, copper, zinc, nickel, cadmium and iron found in water to that in algae (*S. aequinoctialis*) and in soils to that in earthworms (*A. icteria*) in the dry and the rainy season
c) To compare organic matter content in soils, soil pH and water pH for the dry and the rainy season

CHAPTER 2
2.0 MATERIALS AND METHODS

2.1 Description of study area

2.1.1 Location

Malawi is a landlocked, densely populated country located in southeastern Africa. It has Zambia to the north-west, Tanzania to the north and Mozambique surrounding it to the east, south and west (Pearson Education, 2007; Wikipedia, 2007). This study was conducted in the city of Blantyre (Figures 2.1, 2.2 and 2.3), the commercial and industrial capital of Malawi. Blantyre is located in the Shire Highlands in the southern region of Malawi. The most conspicuous and dominant physical features of the district are the numerous hills which are the source of several rivers and streams like Likhubula, Lunzu, Mombezi, Khombwe, Mudi, Chisombezi, Limbe, Luchenza and Mwamphanzi (GoM-SEP, 2002).

2.1.2 Soil and geology

The Shire highlands forms a broad northeasterly trending ridge bordered, to the west, by the plain of the middle Shire and, to the east, by the Phalombe plain. It is formed mainly by a series of charnockitic rocks that are either intermediate or basic in character. The former group predominates and can be further sub-divided into felsic and mafic sub-groups. Interbanded with the charnockitic granulites, is a series of paragneises, which include calcareous and quartzofeldespathic (BCA, 1995).

There are three main types of soil in the district which are the dark clay or reddish brown clay loam soil, clay alluvium deposits mostly found in areas, which are moderately steep and flat along banks and headwaters of rivers and streams and residual soils from pyroxene granulate and systematic gneiss (GoM-SEP, 2002).

2.1.3 Climate

Malawi, in common with greater part of south central Africa, has two main seasons during the year, which are the dry and the wet season. The wet season lasts from November to May and the remainder of the year is dry, with temperatures increasing until the onset of the next rains (BCA, 1995).

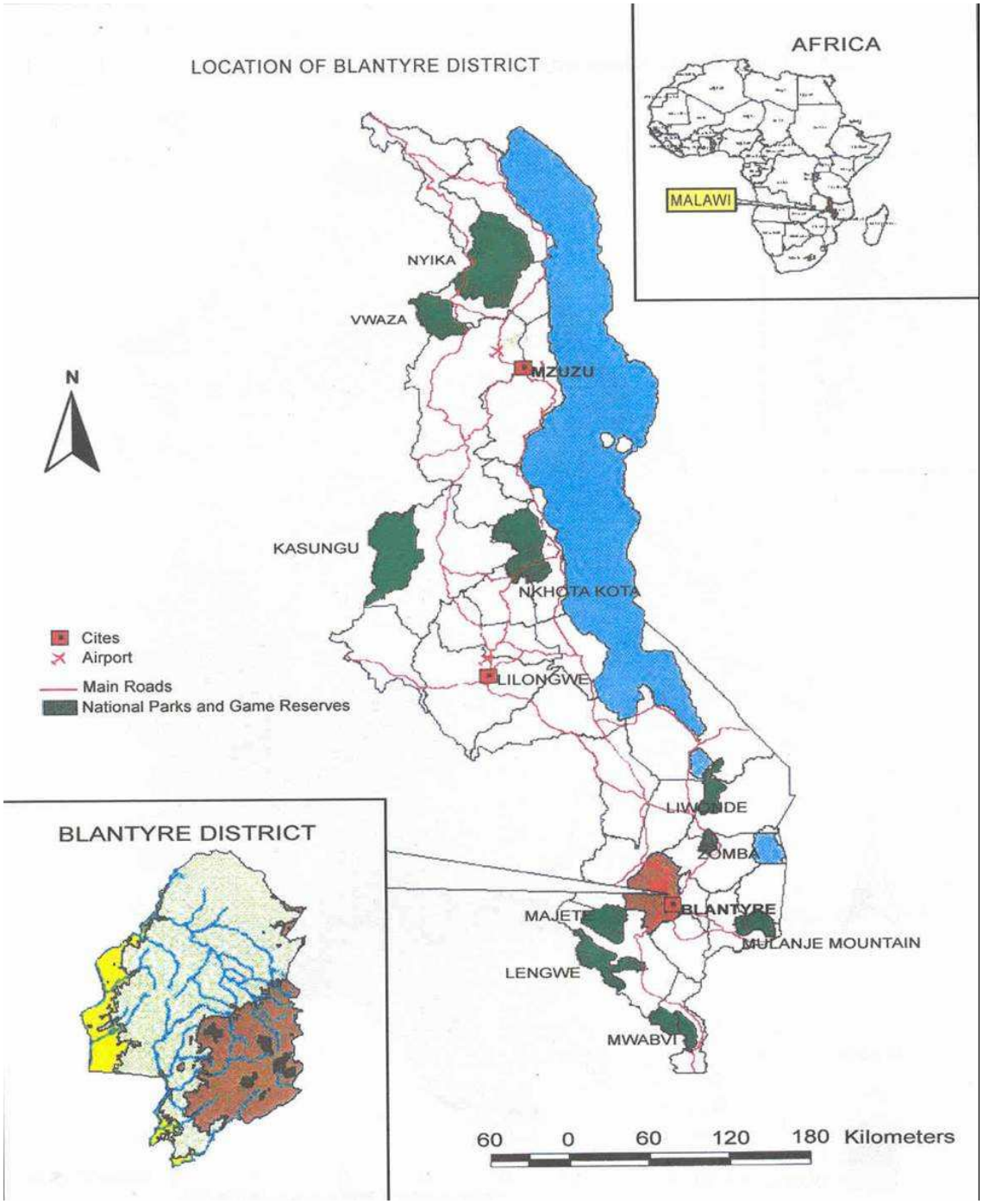


Figure 2.1: Map showing location of Blantyre district (GoM-SEP, 2002)

2.1.4 Vegetation

The district has a savanna type of vegetation (GoM-SEP, 2002). In the past, the Shire Highlands was mostly covered with closed evergreen forest, which has been lost due to clearing for cultivation and energy. This has led to only scattered fragments of the original *Brachstegia* woodland remaining, mostly on private estates and the lower slopes of rocky hills. As much a feature of the landscape today are the many plantations of exotic trees and particularly the ubiquitous blue gum (*Eucalyptus saligna* and *Eucalyptus grandis*). Riverine forest still 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. Typical species of the riverine forest are: *Khaya nyasica* (mbawa), *Parkia filicoidea* (mkundi), *Albizzia glabrescens* (mtangatanga), *Ficus vallischoudae* (mkuyu), and the palms *Raphina vinifera* (ciwale), *Adina microcephala* (mweya), and *Phoenix reclinata* (kanjedza) (BCA, 1995).

2.1.5 Land use system

In Blantyre city, the land (22, 800 ha) is mainly used for urban development which accounts for 10, 242 ha (44.9%) of the total land followed by forest reserves and plantations covering 5, 406 ha (23.7%) and 7, 152 ha (31.4%) undeveloped/undetermined land and open space which is predominantly used for maize production among city residents (Figure 2.2).

2.1.6 Economy

Commerce and Industry

The commerce, trade, and industry sectors are the driving force of economic development in the district. It is by far the major employment generator in Blantyre. Activities under the sector are classified into four categories which are trading, service, manufacturing and agro-based (GoM-SEP, 2002). The major industrial areas are Makata, Chichiri and Maselema. Companies in Blantyre fall under the following categories: textile and leather products, paints, pharmaceuticals and other chemicals, metal and wood processing, petroleum and plastics, power distribution, dairy products and abattoir, beer breweries, tobacco processing and food processing (BCA, 1995).

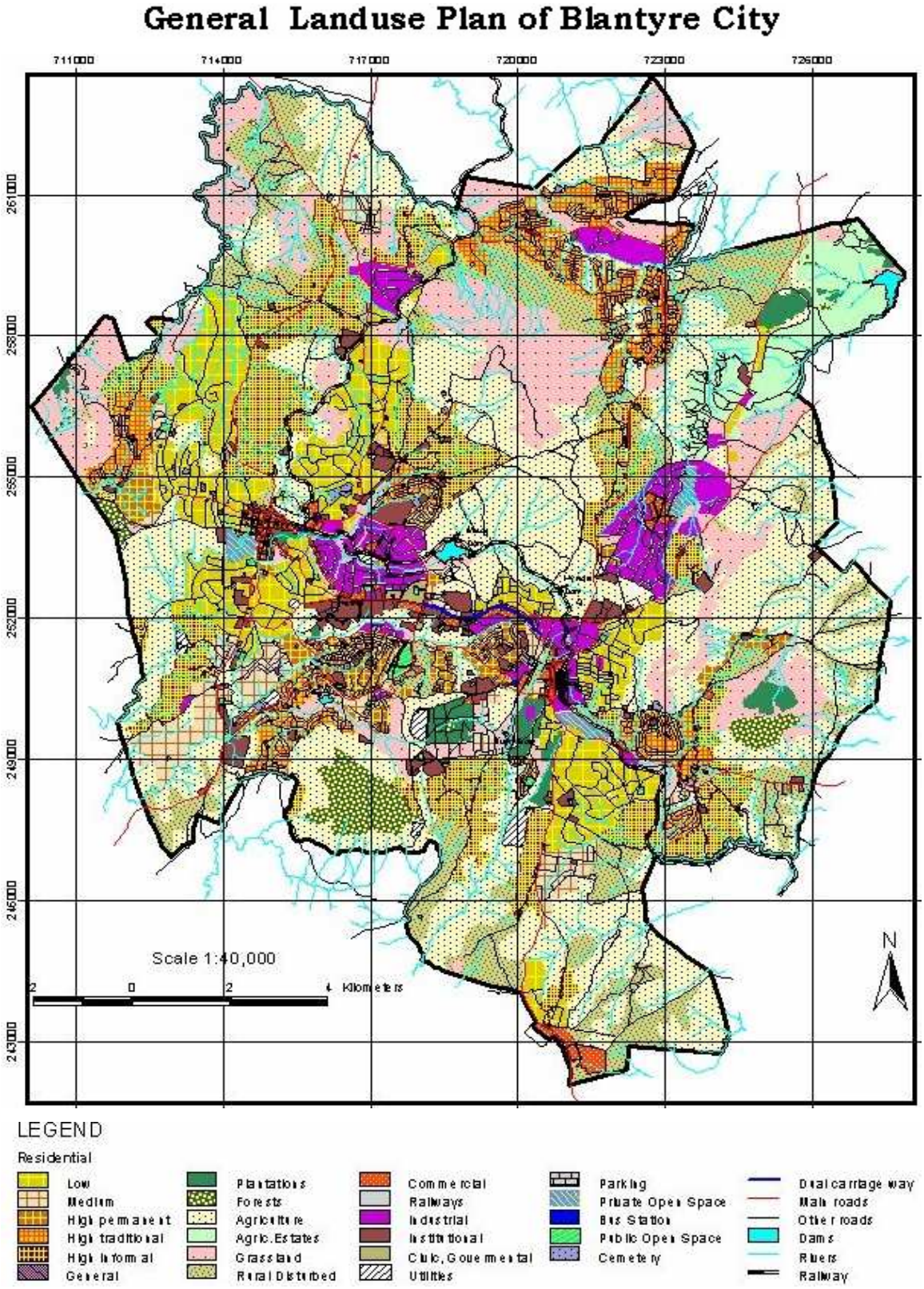


Figure 2.2: Map of Blantyre city showing land use (BCA, 1995)

2.2 Sampling

2.2.1 Sampling sites

The sampling sites fell into two major categories, which were; streams and wastewater treatment plants. The streams sampled were Chirimba, Mudi, Nasolo, Michiru, Mangunda, Limbe and Naperi. Most of these streams pass through the major industrial areas (Figures 2.2 and 2.3) except for Michiru stream, which originates from a forest reserve and Mangunda stream, which originates from Mzedi hill and passes through a dumpsite (This whole area is known as Mzedi). Michiru stream was taken as a reference point. The wastewater treatment plants sampled were Soche, Blantyre and Limbe (Figure 2.3). Except for Mzedi and Michiru, the other sampling points are the ones used by Blantyre City Assembly in their pollution monitoring activities. Figures 1.2, 2.4 and 2.5 show pollution in some of the sampling points.

2.2.2 Water sampling

Water samples were collected in both the dry (July) and rainy season (December). This was done once in each season. Grab sampling was used and a total of forty three water samples were collected for each season. At each sampling point, water samples were collected in triplicates for heavy metal analysis and a single sample for pH analysis. Water samples were collected in 1-litre polyethylene bottles and 1.5 mL concentrated nitric acid (AR) was added to those samples where heavy metals would be determined (APHA, 1985). Water samples were collected at an area where algae were found.

2.2.3 Algae sampling

Algae samples were collected in both the dry and rainy season at the same location as water samples. A total of eighteen algae samples were collected for each season. The types of algae collected were the filamentous green algae (*Spirogyra aequinoctialis)*. The samples were collected in 100 mL plastic bottles (SWRCB, 2005). The algae samples were chilled in a refrigerator pending analysis (NSW, 2002).

2.2.4 Soil sampling

Soil samples were collected in both the dry and rainy season. Soil samples were collected in an area where earthworms were found. A total of eighteen soil samples were collected for each of the seasons. Soil samples were collected within the topsoil range (0-20 cm) using a soil auger since most of the earthworms were found in this region. Five augerings

were collected at each site and were mixed in a bucket before sub sampling (quartering) (Anderson and Ingram, 1993). The samples were collected in plastic bags (MDA, 2005).

2.2.5 Earthworm sampling

Earthworms were collected in the same seasons and location as soil samples above. A total of eighteen earthworm samples were collected in each season. The earthworms were collected in 400 mL plastic bottles into which a few holes were poked on the lid (EMAN, 2004). Location of points onto which earthworms would be found was done by looking for earthworm casts. The earthworms were identified as *Aporrectodea icteria* (Appendix 2). Only reproductively mature earthworms can be identified because of presence of a clitellum. A clitellum is a reproductive part of an earthworm, which is found close to the head region (Worm watch, 2000).

2.3 Analytical Methods

2.3.1 Instrumentation

i. pH meter(s): Glass electrode pH meters model 601A Orion Research digital ionalyzer and model 744 Metrohm pH meter both with pH reading to 0.01 in the range 0 to 14 were used.

ii. Atomic Absorption Spectrophotometer (s) (AAS): Perkin Elmer, AAnalyst 700 and Buck Scientific AAS model 200A were used in the determination of calcium and heavy metals. The fuel used was acetylene gas and air (oxygen) as the oxidant.

2.3.2 Determination of heavy metals in algae (*S. aequinoctialis)* samples

Algae samples were air dried (Hoffman, 1996). The air dried algae samples were dry ashed with nitric (AR) and hydrochloric acid (AOAC, 1990). Thereafter the sample was made up to 50 mL with distilled water in a volumetric flask. The concentration of heavy metals was determined by running samples on AAS.

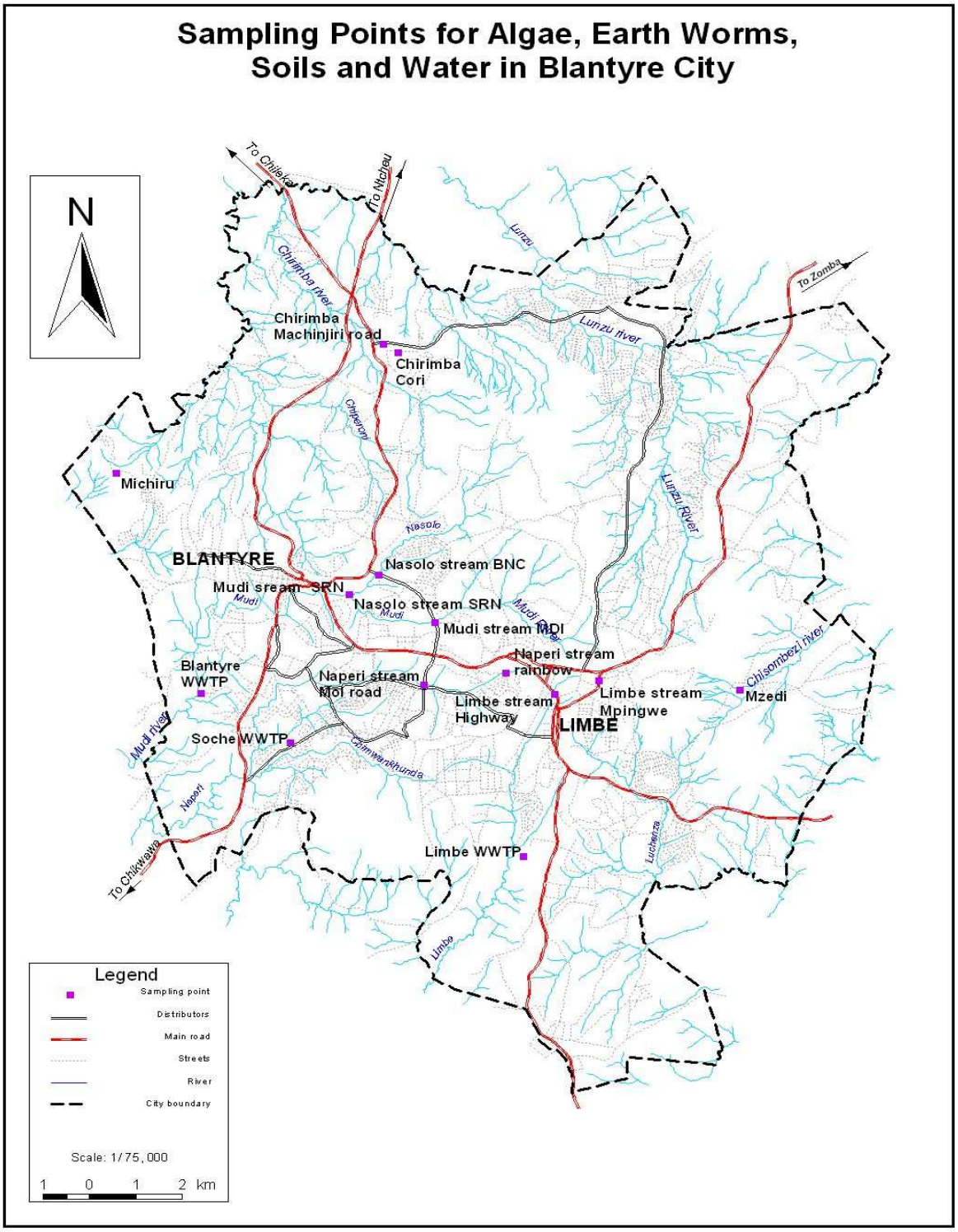


Figure 2.3: Map showing sampling points for algae, earthworms, soils and water in Blantyre city

2.3.3 Determination of heavy metals in earthworm (*A. icteria)* samples

The earthworms were cleaned with distilled water, placed in petri dishes and refrigerated at 10^{o} C for 24 hrs in order to purge the soil in the gut. Thereafter they were removed and rinsed slightly with distilled water and then frozen pending analysis.

In preparing for analysis, after thawing, 3 g of the earthworm sample was weighed and digested with 2 mL concentrated nitric acid and heated to dryness on a hotplate. The digest was redissolved in 1 mL concentrated nitric acid (AR) and filtered after which it was made up to 50 mL with distilled water in a volumetric flask (Bamgbose et al., 2000). The concentration of heavy metals was determined by running samples on AAS.

Figure 2.4: Water with a lot of foam at a confluence of Mudi and Nasolo streams

Figure 2.5: A gully below Mzedi dumpsite, which encourages runoff from the dumpsite to Mangunda stream

2.3.4 Determination of heavy metals in soil samples

The soil samples were air dried and ground in a mortar, then they were passed through a 2 mm sieve, 5 g of the sieved soil sample was weighed and 10 mL concentrated nitric acid (AR) added. The mixture in a beaker was covered with a watch glass and refluxed for 45 min. The watch glass was then removed and the contents in the beaker evaporated to dryness, 5 mL aqua regia (3:1 HCL (AR) and nitric acid (AR) respectively) was added and the suspension filtered. The filtrate was then diluted to volume with distilled water in a 50 mL volumetric flask (Bamgbose et al., 2000). The concentration of heavy metals was determined by running samples on AAS.

2.3.5 Determination of heavy metals in water samples

Water samples were digested using concentrated nitric acid (AR) and filtration was done after digestion (APHA, 1985). The filtrate was then diluted to volume with distilled water in a 50 mL volumetric flask.

2.3.6 Determination of organic matter

The soil samples were ground using a mortar and then passed through a 0.5 mm sieve after which 1.00 g soil was weighed in triplicate and transferred to a 250 mL conical flask. Using a pipette, 10 mL 1N potassium dichromate (AR) solution was added to the

sample. This was followed by 15 mL concentrated sulphuric acid (AR), which was added, from a burette while shaking the flask. The shaking was continued for about one minute then the sample was left undisturbed for thirty minutes. Then about 150 mL water and 5 mL concentrated phosphoric acid (AR) were added whilst shaking the flask. The sample was left for some few minutes to cool. Immediately before the titration, 1 mL diphenylamine indicator (AR) solution was added to the sample. The sample was titrated against 0.5 N ferrous ammonium sulphate (AR) solution. The colour change was from deep blue to dark green. Similarly triplicates of blank titrations were carried out. Where the volume of 0.5 N ferrous ammonium sulphate (AR) solution was less than three, the determinations were repeated using 0.5 g soil and the final answer was multiplied by two. This is known as the Walkley – Black method (BRS, 1990). The percentage organic carbon was found using the following equation;

$$\%C = \frac{(MeK_2Cr_2O_7 - MeFe(NH_4)_2(SO_4)_2.6H_2O) \times 0.0031 \times 100 \times F}{Mass\,(g)\ of\ air\ dried\ soil}$$

Where,

F = Correction factor (1.33)

Me = Normality of solution × mL of solution used

The percentage organic matter in soil = % organic carbon × 1.729

2.3.7 Determination of soil pH

In a beaker, 40 mL of distilled water was added to 40 g of dried and sieved soil. The soil-water mixture was stirred until a complete suspension of soil in water was formed. Stirring of the soil-water mixture was done for thirty seconds every three minutes for a total of five stirring/waiting cycles. Then, the mixture was allowed to settle until a supernatant (clearer liquid above the settled soil) had formed (about five minutes). Then the pH was measured by dipping the electrode (probe) of the pH meter into the supernatant liquid. The pH meter was calibrated by using two buffers of pH 4 and 9 (NSF & SSA, 2001).

2.3.8 Determination of water pH

Water pH was determined by using the standard method as in APHA (1985) and buffers of pH 4 and 9 were used to calibrate the pH meter. The pH was measured on the same day of sampling.

2.3.9 Preparation of standard stock solutions

2.3.9.1 Cadmium

The standard stock solution was prepared by dissolving 1.000 g cadmium metal (AR) in a minimum of 1 + 1 HCL (AR) and diluting to 1000 mL in a volumetric flask to obtain a 1000 mg/L cadmium stock solution. The stock solution was used to prepare a 100 mg/L 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 10.0 mg/L. Absorbance of the working standard was read using AAS at 228.8 nm.

2.3.9.2 Chromium

The standard stock solution was prepared by dissolving 2.828 g anhydrous potassium dichromate (AR), $K_2Cr_2O_7$, in about 200 mL water and adding 1.5 mL concentrated HNO_3 (AR) to complete solution. Diluting to 1000 mL in a volumetric flask a 1000 mg/L chromium stock solution was made. The stock solution was used to prepare a 100 mg/L 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 10.0 mg/L. Absorbance of the working standard was read using AAS at 357.9 nm.

2.3.9.3 Copper

The standard stock solution was prepared by dissolving 1.000 g copper metal (GPR) in 15 mL of 1 + 1 HNO_3 (AR) and diluting to 1000 mL in a volumetric flask to obtain a 1000 mg/L copper stock solution. The stock solution was used to prepare a 100 mg/L 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 10.0 mg/L. Absorbance of the working standard was read using AAS at 324.8 nm.

2.3.9.4 Iron

The standard stock solution was prepared by dissolving 1.000 g iron wire (GPR) in 50 mL of 1 + 1 HNO_3 (AR) and diluting to 1000 mL in a volumetric flask to obtain a 1000 mg/L iron stock solution. The stock solution was used to prepare a 100 mg/L 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 10.0 mg/L. Absorbance of the working standard was read using AAS at 248.3 nm.

2.3.9.5 Lead

The standard stock solution was prepared by dissolving 1.598 g lead nitrate (AR) , $Pb(NO_3)_2$, in about 200 mL water and adding 1.5 mL concentrated HNO_3 (AR) to complete solution. Diluting to 1000 mL in a volumetric flask a 1000 mg/L lead stock solution was made. The stock solution was used to prepare a 100 mg/L 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 10.0 mg/L. Absorbance of the working standard was read using AAS at 283.3 nm.

2.3.9.6 Manganese

The standard stock solution was prepared by dissolving 3.076 g manganous sulfate (AR), $MnSO_4.H_2O$, in about 200 mL water, adding 1.5 mL concentrated HNO_3, to complete solution. Diluting to 1000 mL in a volumetric flask a 1000 mg/L manganese stock solution was made. The stock solution was used to prepare a 100 mg/L 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 10.0 mg/L. Absorbance of the working standard was read using AAS at 279.5 nm.

2.3.9.7 Nickel

The standard stock solution was prepared by dissolving 1.273 g nickel oxide (GPR), NiO, in a minimum volume of 10% (v/v) HCl and diluting to 1000 mL in a volumetric flask to obtain a 1000 mg/L nickel stock solution. The stock solution was used to prepare a 100 mg/L 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 10.0 mg/L. Absorbance of the working standard was read using AAS at 232.0 nm.

2.3.9.8 Zinc

The standard stock solution was prepared by dissolving 1.000 g zinc metal (AR) in 20 mL 1 +1 HCl and diluting to 1000 mL in a volumetric flask to obtain a 1000 mg/L zinc stock solution. The stock solution was used to prepare a 100 mg/L 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 10.0 mg/L. Absorbance of the working standard was read using AAS at 213.9 nm.

2.4 Data analysis

The Statistical Package for Social Scientists (SPSS) windows program, version 9.0 (Independent sample t- test) and Microsoft Excel windows program (correlations and graphs) were used to analyze data for the samples collected. Independent sample t-test was chosen because it was assumed that the sampling points were independent of each other same as the seasons. Pearson correlations were used because it was assumed that the levels of heavy metals in water and soils were linearly related to those found in biota.

CHAPTER 3

3.0 RESULTS AND DISCUSSIONS

3.1 Heavy metal levels

3.1.1 Manganese levels in water and algae

In the rainy season, the range of concentration for manganese in water samples was from below detection limit to 0.530 mg/L. In dry season the range of concentration for manganese was 0.035 - 0.626 mg/L (Table 3.1). Water samples indicated significantly higher levels of manganese in the dry season than in the rainy season ($p < 0.05$, Appendix 3, Table 1) which could be attributed to dilution. The value of manganese in water at Mangunda stream in the rainy season was the only one above MBS (0.05- 0.1 mg/L) and WHO (0.5 mg/L) drinking water standards. The possible source of manganese for Mangunda stream is surface runoff from the dumpsite (Figure 2.4). In the dry season 83% of the sampling points showed manganese levels above MBS range with 17% above WHO standards. The possible sources of manganese pollution for the areas that showed levels above standards in the dry season are metal manufacturing industries, power plants, fertilizers and wastes (Section 2.1.5, Section 2.1.6, Figure 2.2 and Figure 2.3).

In the rainy season, the range of manganese concentration in filamentous green algae (*S. aequinoctialis*) was 0.432 - 5.641 mg/kg while in the dry season it was 0.281 - 16.132 mg/kg (Table 3.1). *S. aequinoctialis* samples indicated significantly higher levels of manganese in the dry season than in the rainy season ($p < 0.05$, Appendix 3, Table 1). Water and *S. aequinoctialis* samples manganese levels were not strongly correlated for both seasons ($r = 0.298$ for rainy season (an indication that as the levels of manganese were increasing in water, so were the levels in *S. aequinoctialis*) and $r = -0.215$ for dry season (an indication that as levels of manganese were decreasing in water, in *S. aequinoctialis* they were increasing)). However *S. aequinoctialis* samples indicated significantly higher manganese levels when compared to water samples for both seasons ($p < 0.05$, Appendix 3, Table 1). The concentration of manganese in both water and *S. aequinoctialis* at Michiru stream, which is in a forest reserve was not different from most of the places, however it was not among the highest values indicating that the other

sampling places could have been polluted by anthropogenic sources. The possible sources of manganese for Michiru stream are deposition and rocks. The highest level of manganese in *S. aequinoctialis* recorded at Limbe stream at Mpingwe could be from fertilizers since there are gardens close to the stream. The water and *S. aequinoctialis* results agreed with studies done elsewhere. Pederson and Vaultonburg (1996) found the mean level of manganese found in water sampled from Embarras river, Illinois, USA to be in the range 0.082 – 0.464 mg/L while in attached algae sampled in the same area to be 391 – 4260 mg/kg.

Table 3.1: Manganese levels in water and algae

Sampling point	Manganese levels in water for rainy season (mg/L)	Manganese levels in water for dry season (mg/L)	Manganese levels in algae for rainy season (mg/kg)	Manganese levels in algae for dry season (mg/kg)
Chirimba stream at Cori	ND	0.035 ± 0.014	3.185 ± 0.931	3.351 ± 0.541
Chirimba stream at Machinjiri road	ND	0.155 ± 0.07	1.903 ± 0.284	0.522 ± 0.123
Mudi stream at MDI	0.060 ± 0.028	0.244 ± 0.01	5.641 ± 0.963	4.875 ± 1.112
Mudi stream at SRN	ND	0.178 ± 0.04	1.782 ± 0.491	13.521 ± 1.088
Soche WWTP raw sewage	ND	0.365 ± 0.027	1.438 ± 0.196	4.203 ± 0.805
Soche WWTP effluent	ND	0.384 ± 0.029	0.586 ± 0.168	0.281 ± 0.142
Blantyre WWTP raw sewage	ND	0.435 ± 0.011	0.432 ± 0.075	3.862 ± 0.335
Blantyre WWTP effluent	ND	0.453 ± 1.034	0.731 ± 0.406	7.393 ± 2.654
Nasolo stream at BNC	ND	0.42 ± 0.029	1.725 ± 0.533	4.213 ± 1.018
Nasolo stream at SRN	ND	0.457 ± 0.018	2.333 ± 1.452	5.061 ± 0.198
Michiru stream	ND	0.056 ± 0.001	3.817 ± 0.601	2.399 ± 0.544
Mangunda stream	0.530 ± 0.121	0.489 ± 0.006	3.968 ± 1.098	12.421 ± 1.711
Limbe WWTP effluent	ND	0.511 ± 0.015	0.860 ± 0.456	0.793 ± 0.117
Limbe WWTP raw sewage	ND	0.626 ± 0.041	2.769 ± 1.586	2.065 ± 0.408
Limbe stream at Mpingwe	ND	0.049 ± 0.131	3.599 ± 1.586	16.132 ± 1.527
Limbe stream at Highway	ND	0.168 ± 0.008	3.950 ± 0.998	4.405 ± 1.203
Naperi stream at Rainbow paints	ND	0.585 ± 0.012	4.634 ± 1.289	3.401 ± 0.467
Naperi stream at Moi road	ND	0.464 ± 0.004	1.913 ± 0.2	7.164 ± 0.842

MBS manganese drinking water standard (0.05- 0.1 mg/L)
WHO manganese drinking water standard (0.5 mg/L)
Algae data is on dry basis
Values are in the form of mean ± standard deviation

3.1.2 Cadmium levels in water and algae

In the rainy season, the range of concentration for cadmium in water samples was 0.07 – 0.111 mg/L while in the dry season it was 0.014 – 0.111 mg/L (Table 3.2). Water samples indicated no significant differences for rainy and dry season cadmium levels ($p > 0.05$, Appendix 3, Table 2). In both seasons all the sampling points indicated water cadmium levels above MBS (0.003 – 0.005 mg/L) and WHO (0.003 mg/L) standards for drinking water. The possible sources of cadmium pollution for the streams in Blantyre are metal processing operations, burning fossil fuels, making and using phosphate fertilizers, and disposing of metal products (Section 2.1.5, Section 2.1.6, Figure 2.2 and Figure 2.3).

The filamentous green algae (*S. aequinoctialis*) rainy season cadmium concentration range was from below detection limit to 0.035 mg/kg while in the dry season it was 0.22 – 0.912 mg/kg (Table 3.2). *S. aequinoctialis* samples indicated significantly higher levels of cadmium in the dry season than in the rainy season ($p < 0.05$, Appendix 3, Table 2). Water and *S. aequinoctialis* samples cadmium levels were not strongly correlated for both seasons ($r = -0.255$ for rainy season (an indication that as the levels of cadmium in water were increasing, the levels in *S. aequinoctialis* were decreasing) and $r = 0.296$ for dry season (an indication that as the levels of cadmium in water were increasing, so were the levels in *S. aequinoctialis*)). In comparing water samples to *S. aequinoctialis* samples cadmium for both seasons, there were significant differences ($p < 0.05$, Appendix 3, Table 2). Water samples had high cadmium levels in the rainy season while in the dry season the levels were higher in *S. aequinoctialis*. The high cadmium values in water samples for rainy season could have come from surface runoff. The concentration of cadmium in both water and S. aequinoctialis at Michiru stream was not different from most of the places. This could be attributed to deposition and rocks. The highest level of cadmium in *S. aequinoctialis* at Blantyre WWTP (raw sewage) is from industries. This is because Blantyre WWTP handles industrial wastewater. It was only dry season water and *S. aequinoctialis* results of cadmium that agreed with studies done on the river Danube. Chmielewska and Medved (2001) found mean cadmium levels in lagoon water situated on the left bank of the river Danube to be 0.005 mg/L and in green algae (*Cladophora glomerata*) sampled in that water to be 0.1 mg/kg.

Table 3.2: Cadmium levels in water and algae

Sampling point	Cadmium levels in water for rainy season (mg/L)	Cadmium levels in water for dry season (mg/L)	Cadmium levels in algae for rainy season (mg/kg)	Cadmium levels in algae for dry season (mg/kg)
Chirimba stream at Cori	0.073 ± 0.005	0.037 ± 0.005	0.018 ± 0.135	0.291 ± 0.013
Chirimba stream at Machinjiri road	0.073 ± 0.004	0.041 ± 0.003	0.029 ± 0.013	0.054 ± 0.001
Mudi stream at MDI	0.111 ± 0.031	0.052 ± 0.137	ND	0.362 ± 0.041
Mudi stream at SRN	0.085 ± 0.003	0.047 ± 0.011	ND	0.171 ± 0.008
Soche WWTP raw sewage	0.089 ± 0.003	0.111 ± 0.013	ND	0.836 ± 0.078
Soche WWTP effluent	0.087 ± 0.003	0.087 ± 0.009	ND	0.142 ± 0.031
Blantyre WWTP raw sewage	0.081 ± 0.002	0.092 ± 1.002	ND	0.912 ± 0.012
Blantyre WWTP effluent	0.082 ± 0.003	0.075 ± 0.018	ND	0.044 ± 0.018
Nasolo stream at BNC	0.082 ± 0.004	0.079 ± 0.017	0.024 ± 0.403	0.468 ± 0.031
Nasolo stream at SRN	0.08 ± 0.008	0.098 ± 1.016	0.035 ± 1.062	0.022 ± 0.142
Michiru stream	0.086 ± 0.002	0.014 ± 0.001	ND	0.393 ± 0.017
Mangunda stream	0.09 ± 0.003	0.102 ± 0.007	0.022 ± 1.463	0.586 ± 0.047
Limbe WWTP effluent	0.077 ± .002	0.065 ± 0.104	ND	0.796 ± 0.141
Limbe WWTP raw sewage	0.08 ± 0.004	0.018 ± 2.101	ND	0.082 ± 0.013
Limbe stream at Mpingwe	0.07 ± 0.002	0.0614 ± 1.114	ND	0.074 ± 0.034
Limbe stream at Highway	0.072 ± 0.004	0.095 ± 0.180	ND	0.428 ± 0.153
Naperi stream at Rainbow paints	0.081 ± 0.003	0.089 ± 1.982	0.016 ± 0.217	0.039 ± 0.019
Naperi stream at Moi road	0.082 ± 0.001	0.092 ± 1.089	ND	0.116 ± 0.042

MBS cadmium drinking water standard (0.003 – 0.005 mg/L)
WHO cadmium drinking water standard (0.003 mg/L)
Algae data is on dry basis
Values are in the form of mean ± standard deviation

3.1.3 Copper levels in water and algae

In the rainy season all the water samples indicated copper concentration below detection limit while in the dry season copper concentration ranged from below detection limit to 0.076 mg/L (Table 3.3). Water samples indicated significantly higher levels of copper in dry season as compared to rainy season. ($p < 0.05$, Appendix 3, Table 3). This could be due to the effect of dilution. In both seasons all the water samples indicated copper values below MBS (0.5 – 1 mg/L) and WHO (2 mg/L) standards. The possible sources of copper pollution for Blantyre streams are combustion of fossil fuels, metal production, wood production and phosphate fertilizer production (Section 2.1.5, Section 2.1.6, Figure 2.2 and Figure 2.3).

In the rainy season, for the filamentous green algae (*S. aequinoctialis*), the range of copper concentration was 0.002 - 0.826 mg/kg while in the dry season it was 0.056 - 2.302 mg/kg (Table 3.3). *S. aequinoctialis* samples indicated significantly higher levels of copper in the dry season than the rainy season ($p < 0.05$, Appendix 3, Table 3). Water and *S. aequinoctialis* samples correlation coefficient (r) for rainy season could not be computed since all water samples indicated copper values below detection limit while in the dry season the correlation was not strong ($r = 0.171$(an indication that as the levels of copper in water were increasing for this season, so were the levels in *S. aequinoctialis*)). However *S. aequinoctialis* samples indicated significantly higher levels of copper for both seasons when compared to water samples ($p < 0.05$, Appendix 3, Table 3). The concentration of copper in water at Michiru stream in both seasons was below detection limit (indicating possible pollution by anthropogenic sources for the other sampling areas). The concentration of copper at Michiru stream for *S. aequinoctialis* in the rainy season was the lowest with the dry season value not different from most of the places. The dry season value could be as a result of deposition and rocks. The high concentration found in *S. aequinoctialis* at Limbe WWTP could be from industries since this treatment plant handles industrial wastewater. The water and *S. aequinoctialis* results agreed with studies done in United Kingdom where Black and Mitchel (1952) found the mean level of copper in seawater collected at Atlantic bridge between the Island of Seil and Scotland to be below detection limit while the mean level in brown algae (*F. serratus*) was 1.2 mg/kg.

Table 3.3: Copper levels in water and algae

Sampling point	Copper levels in water for rainy season (mg/L)	Copper levels in water for dry season (mg/L)	Copper levels in algae for rainy season (mg/kg)	Copper levels in algae for dry season (mg/kg)
Chirimba stream at Cori	ND	0.046 ± 0.037	0.563 ± 0.067	0.313 ± 0.065
Chirimba stream at Machinjiri road	ND	0.023 ± 0.002	0.129 ± 0.009	0.154 ± 0.124
Mudi stream at MDI	ND	0.006 ± 0.022	0.091 ± 0.035	0.171 ± 0.023
Mudi stream at SRN	ND	0.045 ± 0.109	0.223 ± 0.029	0.105 ± 0.041
Soche WWTP raw sewage	ND	0.065 ± 0.892	0.374 ± 0.064	0.196 ± 0.031
Soche WWTP effluent	ND	0.054 ± 0.003	0.299 ± 0.052	0.175 ± 0.136
Blantyre WWTP raw sewage	ND	0.076 ± 0.153	0.826 ± 0.237	1.804 ± 0.201
Blantyre WWTP effluent	ND	0.044 ± 0.113	0.265 ± 0.039	0.614 ± 0.335
Nasolo stream at BNC	ND	0.038 ± 0.293	0.113 ± 0.012	0.056 ± 1.032
Nasolo stream at SRN	ND	0.064 ± 1.113	0.122 ± 0.095	1.498 ± 0.417
Michiru stream	ND	ND	0.002 ± 0.012	0.605 ± 0.386
Mangunda stream	ND	0.018 ± 2.314	0.026 ± 0.02	0.326 ± 0.026
Limbe WWTP effluent	ND	ND	0.229 ± 0.07	0.223 ± 0.041
Limbe WWTP raw sewage	ND	0.013 ± 1.018	0.092 ± 0.016	2.302 ± 0.135
Limbe stream at Mpingwe	ND	ND	0.029 ± 0.02	0.551 ± 0.310
Limbe stream at Highway	ND	0.016 ± 0.007	0.09 ± 0.036	0.123 ± 0.052
Naperi stream at Rainbow paints	ND	ND	0.225 ± 0.04	0.596 ± 0.102
Naperi stream at Moi road	ND	0.025 ± 1.015	0.077 ± 0.037	1.418 ± 0.426

MBS copper drinking water standard (0.5 – 1 mg/L)
WHO copper drinking water standard (2 mg/L)
Algae data is on dry basis
Values are in the form of mean ± standard deviation

3.1.4 Iron levels in water and algae

In the rainy season, iron concentration in water samples was from below detection limit to 3.209 mg/L while in the dry season the range was 0.372 - 2.282 mg/L (Table 3.4). There was no significant difference for rainy season and dry season water samples iron values ($p > 0.05$, Appendix 3, Table 4). In the rainy season 78% of the water samples showed iron levels above MBS (0.01 – 0.2 mg/L) standards for drinking water while only 6% of the sampling points showed iron levels above WHO (1 – 3 mg/L, suggested but not used value) standards for drinking water. In the dry season all the water samples indicated iron levels above MBS standards with none of the sampling points giving values above WHO standards. The possible sources of iron pollution for Blantyre streams are metal processing industries and waste disposal (Section 2.1.6, Figure 2.2 and Figure 2.3).

In the filamentous green algae (*S. aequinoctialis*), the rainy season range of iron concentration was 30.75 - 81.36 mg/kg while in the dry season it was 13.825 - 96.641 mg/kg (Table 3.4). In comparing the levels of iron in *S. aequinoctialis* for rainy season to those in dry season, there was no significant difference ($p > 0.05$, Appendix 3, Table 4). Water and *S. aequinoctialis* samples iron levels were not strongly correlated for both seasons ($r = 0.453$ for rainy season and $r = 0.038$ for dry season (an indication that as the levels of iron were increasing in water for both seasons, so were the levels in *S. aequinoctialis*)). However *S. aequinoctialis* samples indicated significantly higher levels of iron for both seasons when compared to water samples ($p < 0.05$, Appendix 3, Table 4). The concentration of iron in both water and *S. aequinoctialis* at Michiru for both seasons was not different from most of the places. This could be due to deposition and rocks. The highest concentration of iron in S. *aequinoctialis* at Blantyre WWTP is attributed to industries. The water and *S. aequinoctialis* results agreed with studies done elsewhere. Black and Mitchel (1952) found the mean level of iron in seawater collected at Atlantic bridge between Island of Seil and Scotland to be below detection limit while in brown algae (*F. serratus*) the mean level was 62 mg/kg. Pederson and Vaultonburg (1996) found the mean level of iron in water sampled from Embarras river, Illinois, USA to be in the range 0.57 – 3.47 mg/L while in attached algae sampled in the same area to be 10400 – 29400 mg/kg.

Table 3.4: Iron levels in water and algae

Sampling point	Iron levels in water for rainy season (mg/L)	Iron levels in water for dry season (mg/L)	Iron levels in algae for rainy season (mg/kg)	Iron levels in algae for dry season (mg/kg)
Chirimba stream at Cori	1.091 ± 0.165	1.944 ± 0.083	71.35 ± 3.476	35.975 ± 0.437
Chirimba stream at Machinjiri road	1.197 ± 0.233	1.677 ± 0.066	65.21 ± 4.453	64.215 ± 1.621
Mudi stream at MDI	0.614 ± 0.887	0.575 ± 0.120	60.293 ± 3.809	13.825 ± 0.926
Mudi stream at SRN	3.209 ± 1.165	1.675 ± 0.054	72.42 ± 2.461	70.905 ± 2.381
Soche WWTP raw sewage	ND	0.543 ± 0.143	34.667 ± 1.679	35.815 ± 1.451
Soche WWTP effluent	ND	0.372 ± 0.064	32.055 ± 1.435	26.413 ± 1.141
Blantyre WWTP raw sewage	0.151 ± 0.014	0.902 ± 0.224	38.75 ± 1.557	96.641 ± 1.038
Blantyre WWTP effluent	0.177 ± 0.089	0.608 ± 0.017	31.995 ± 4.830	44.055 ± 0.941
Nasolo stream at BNC	0.785 ± 0.122	0.904 ± 0.472	70.255 ± 3.09	71.712 ± 2.713
Nasolo stream at SRN	0.759 ± 0.192	2.277 ± 0.249	75.875 ± 5.834	20.092 ± 0.311
Michiru stream	1.024 ± 0617	0.409 ± 0.034	56.355 ± 4.561	25.805 ± 1.025
Mangunda stream	1.022 ± 0.945	0.473 ± 0.331	51.54 ± 5.784	43.745 ± 0.541
Limbe WWTP effluent	0.663 ± 0.317	2.282 ± 0.239	30.75 ± 2.956	64.405 ± 1.773
Limbe WWTP raw sewage	0.708 ± 0.209	0.661 ± 0.261	66.695 ± 4.844	84.931 ± 1.632
Limbe stream at Mpingwe	1.084 ± 0.063	2.191 ± 0.712	63.415 ± 1.096	16.315 ± 0.419
Limbe stream at Highway	1.14 ± 0.234	1.255 ± 0.176	69.735 ± 4.759	57.132 ± 0.054
Naperi stream at Rainbow paints	0.290 ± 0.256	2.134 ± 0.498	81.36 ± 0.394	63.005 ± 0.716
Naperi stream at Moi road	0.168 ± 0.103	1.070 ± 0.507	69.525 ± 1.209	31.155 ± 1.246

MBS iron drinking water standard (0.01 – 0.2 mg/L)
WHO iron drinking water standard (1 – 3 mg/L, suggested but not used value)
Algae data is on dry basis
Values are in the form of mean ± standard deviation

3.1.5 Zinc levels in water and algae

In the rainy season, the range of zinc concentration in water samples was 0.502 - 2.614 mg/L while in the dry season it was 0.102 - 0.403 mg/L (Table 3.5). Water samples in the rainy season indicated significantly higher levels of zinc as compared to the dry season ($p < 0.05$, Appendix 3, Table 5). The high levels of zinc in the rainy season could have come from surface run-off from metal processing industries and open dumpsites. For both seasons the range of zinc was below MBS (3.0 – 5.0mg/L) and WHO (3mg/L, suggested but not used value) drinking water standards. The possible sources of zinc pollution for Blantyre streams are iron and steel industries where zinc is used as a galvanizing element, battery manufacturing industries and waste disposal (Section 2.1.5, Section 2.1.6, Figure 2.2 and Figure 2.3).

In rainy season, the range of zinc concentration in filamentous green algae (*S. aequinoctialis*) was 0.202 - 3.270 mg/kg while in the dry season it was 0.203 -6.188 mg/kg (Table 3.5). In comparing *S. aequinoctialis* zinc levels for rainy season to dry season, there was no significant difference ($p > 0.05$, Appendix 3, Table 5). Water and *S. aequinoctialis* samples zinc levels were not strongly correlated for both seasons ($r = 0.255$ for rainy season (an indication that as the levels of zinc were increasing in water, so were the levels in *S. aequinoctialis*) and $r = -0.200$ for dry season (an indication that as the levels of zinc were decreasing in water, in *S. aequinoctialis* they were increasing)). *S. aequinoctialis* samples indicated significantly higher zinc values for both seasons when compared to water samples ($p < 0.05$, Appendix 3, Table 5). The concentration of zinc in water at Michiru was not different from most of the places. However the concentration of zinc in *S. aequinoctialis* in both seasons was the lowest which could indicate that zinc levels for the other areas is mainly from anthropogenic sources. The highest concentration of zinc in *S. aequinoctialis* at Blantyre WWTP is attributed to industries. The water and *S. aequinoctialis* results agreed with studies done elsewhere. Black and Mitchel (1952) found that the mean level of zinc in seawater collected at Atlantic bridge between Island of Seil and Scotland was 0.009 mg/L while in brown algae (*F. serratus*) it was 12 mg/kg. Pederson and Vaultonburg (1996) found the mean level of zinc sampled in water from Embarras river, Illinois, USA to be below detection limit while in attached algae sampled in the same area to be 45 – 125 mg/kg.

Table 3.5: Zinc levels in water and algae

Sampling point	Zinc levels in water for rainy season (mg/L)	Zinc levels in water for dry season (mg/L)	Zinc levels in algae for rainy season (mg/kg)	Zinc levels in algae for dry season (mg/kg)
Chirimba stream at Cori	0.502 ± 0.056	0.295 ± 0.240	2.828 ± 0.231	3.035 ± 0.125
Chirimba stream at Machinjiri road	0.558 ± 0.164	0.148 ± 0.047	1.393 ± 0.333	0.351 ± 0.123
Mudi stream at MDI	1.494 ± 0.002	0.116 ± 0.057	1.16 ± 0.611	1.258 ± 0.047
Mudi stream at SRN	2.614 ± 3.521	0.102 ± 0.019	2.734 ± 0.328	2.263 ± 1.334
Soche WWTP raw sewage	0.703 ± 0.183	0.233 ± 0.031	2.993 ± 0.640	2.603 ± 0.072
Soche WWTP effluent	0.711 ± 0.187	0.195 ± 0.157	3.270 ± 0.149	2.621 ± 1.209
Blantyre WWTP raw sewage	0.674 ± 0.034	0.173 ± 0.038	2.018 ± 0.512	6.188 ± 0.527
Blantyre WWTP effluent	0.742 ± 0.111	0.135 ± 0.061	1.241 ± 0.222	2.149 ± 0.893
Nasolo stream at BNC	1.079 ± 0.134	0.133 ± 0.012	2.289 ± 0.472	4.426 ± 1.244
Nasolo stream at SRN	0.951 ± 0.133	0.159 ± 0.050	1.915 ± 0.707	1.744 ± 0.124
Michiru stream	0.526 ± 0.038	0.139 ± 0.032	0.202 ± 0.159	0.203 ± 0.091
Mangunda stream	0.503 ± 0.066	0.151 ± 0.069	0.594 ± 0.595	0.922 ± 0.024
Limbe WWTP effluent	0.675 ± 0.09	0.291 ± 0.285	2.855 ± 0.039	0.726 ± 0.124
Limbe WWTP raw sewage	0.629 ± 0.056	0.264 ± 0.113	0.936 ± 0.678	0.459 ± 0.073
Limbe stream at Mpingwe	0.562 ± 0.019	0.403 ± 0.332	0.923 ± 0.767	0.496 ± 0.043
Limbe stream at Highway	0.633 ± 0.116	0.172 ± 0.028	2.436 ± 0.378	1.751 ± 0.381
Naperi stream at Rainbow paints	0.714 ± 0.103	0.143 ± 0.035	1.774 ± 0.308	5.358 ± 1.134
Naperi stream at Moi road	0.621 ± 0.064	0.119 ± 0.002	0.230 ± 0.005	0.988 ± 0.403

MBS zinc drinking water standard (3.0 – 5.0mg/L)
WHO zinc drinking water standard (3mg/L, suggested but not used value)
Algae data is on dry basis
Values are in the form of mean ± standard deviation

3.1.6 Lead levels in water and algae

In the rainy season, the range of concentration for lead in water samples was 0.011 - 0.098 mg/L while in the dry season it was from below detection limit to 0.23 mg/L (Table 3.6). Water samples indicated no significant differences for lead in rainy and dry season ($p > 0.05$, Appendix 3, Table 6). In the rainy season 44% of the sampling points indicated lead levels above MBS (0.01 – 0.05 mg/L) and WHO (0.01 mg/L) drinking water standards while in the dry season it was 61% of the sampling points. The possible sources of lead pollution for Blantyre streams are vehicle emissions, industries like those involved in the manufacturing of lead-acid batteries and waste disposal (Section 2.1.5, Section 2.1.6, Figure 2.2 and Figure 2.3).

In the rainy season, the range of lead concentration in filamentous green algae (*S. aequinoctialis*) was from below detection limit to 0.965 mg/kg while in the dry season it was from below detection limit to 0.972 mg/kg (Table 3.6). *S. aequinoctialis* samples indicated no significant differences for rainy season and dry season lead values ($p > 0.05$, Appendix 3, Table 6). Water and *S. aequinoctialis* samples lead levels were strongly correlated in the rainy season than in the dry season ($r = 0.570$ for rainy season and $r = 0.473$ for dry season (indicating that as iron levels were increasing in water for both seasons, so were the levels in *S. aequinoctialis*)). *S. aequinoctialis* samples indicated significantly higher lead values for both seasons when compared to water samples ($p < 0.05$, Appendix 3, Table 6). In the rainy season the concentration of lead in water for Michiru stream was the second lowest and in dry season water lead concentration was below detection limit. In *S. aequinoctialis* for both seasons lead concentration at Michiru stream was below detection limit. This indicates that lead concentration for the other areas was due to anthropogenic sources. The high lead concentration at Mudi and Nasolo streams at SRN is attributed to industries. The water and *S. aequinoctialis* results agreed with studies done elsewhere. Chmielewska and Medved (2001) found the mean level of lead to be 0.023 mg/L in lagoon water situated on the left bank of the river Danube and 7.9mg/kg in green algae (*C. glomerata*) found in the same water. Black and Mitchel (1952) found that the mean level of lead in seawater collected at Atlantic bridge between Island of Seil and Scotland was 0.008 mg/L while in brown algae (*F. serratus*) it was 0.78 mg/kg.

Table 3.6: Lead levels in water and algae

Sampling point	Lead levels in water for rainy season (mg/L)	Lead levels in water for dry season (mg/L)	Lead levels in algae for rainy season (mg/kg)	Lead levels in algae for dry season (mg/kg)
Chirimba stream at Cori	0.037 ± 0.001	0.026 ± 0.015	ND	0.194 ± 0.068
Chirimba stream at Machinjiri road	0.035 ± 0.002	0.108 ± 0.004	0.132 ± 0.031	0.121 ± 0.063
Mudi stream at MDI	0.038 ± 0.014	0.079 ± 0.014	0.198 ± 0.132	0.704 ± 0.126
Mudi stream at SRN	0.064 ± 0.048	0.091 ± 0.043	0.266 ± 0.204	0.972 ± 0.012
Soche WWTP raw sewage	0.042 ± 0.016	0.110 ± 0.007	0.174 ± 0.100	0.782 ± 0.013
Soche WWTP effluent	0.058 ± 0.013	0.014 ± 0.010	ND	0.042 ± 0.001
Blantyre WWTP raw sewage	0.047 ± 0.011	0.061 ± 0.006	ND	0.186 ± 0.093
Blantyre WWTP effluent	0.034 ± 0.008	0.052 ± 0.032	ND	0.224 ± 0.016
Nasolo stream at BNC	0.069 ± 0.039	0.092 ± 0.041	0.702 ± 0.076	0.423 ± 0.072
Nasolo stream at SRN	0.074 ± 0.015	0.048 ± 0.011	0.965 ± 0.076	0.071 ± 0.031
Michiru stream	0.012 ± 0.003	ND	ND	ND
Mangunda stream	0.098 ± 0.014	0.102 ± 0.017	0.523 ± 0.005	0.376 ± 0.012
Limbe WWTP effluent	0.074 ± 0.002	ND	0.141 ± 0.016	ND
Limbe WWTP raw sewage	0.065 ± 0.013	0.04 ± 0.001	0.162 ± 0.102	0.323 ± 0.094
Limbe stream at Mpingwe	0.033 ± 0.019	0.23 ± 0.019	ND	0.406 ± 0.072
Limbe stream at Highway	0.089 ± 0.006	0.083 ± 0.015	0.351 ± 0.076	0.475 ± 0.024
Naperi stream at Rainbow paints	0.011 ± 0.002	0.039 ± 0.012	0.263 ± 0.132	0.461 ± 0.068
Naperi stream at Moi road	0.038 ± 0.004	0.057 ± 0.011	0.14 1± 0.011	0.037 ± 0.008

MBS lead drinking water standard (0.01 – 0.05mg/L)
WHO lead drinking water standard (0.01mg/L)
Algae data is on dry basis
Values are in the form of mean ± standard deviation

3.1.7 Chromium levels in water and algae

In the rainy season all water samples indicated chromium concentration below detection limit while in the dry season the concentration ranged from below detection limit to 0.419 mg/L (Table 3.7). Water samples indicated no significant differences for chromium in dry season and rainy season ($p > 0.05$, Appendix 3, Table 7). In the rainy season all water samples indicated chromium levels below MBS (0.05 – 0.1 mg/L) and WHO (0.05mg/L) drinking water standards. In the dry season 17% of the water samples indicated chromium levels above MBS and WHO drinking water standards. The possible sources of chromium pollution for Blantyre streams are industries involved in steel, leather and textile manufacturing and waste disposal (Section 2.1.5, Section 2.1.6, Figure 2.2 and Figure 2.3).

In the rainy season, the concentration of chromium in filamentous green algae (*S. aequinoctialis*) ranged from below detection limit to 0.431 mg/kg while in the dry season the range was from below detection limit to 0.663 mg/kg (Table 3.7). *S. aequinoctialis* samples indicated no significant differences for dry season and rainy season chromium values ($p > 0.05$, Appendix 3, Table 7). Water and *S. aequinoctialis* samples rainy season correlation coefficient (r) could not be computed since all water samples indicated chromium levels below detection limit while in the dry season the samples were strongly correlated ($r = 0.817$(indicating that as the levels of chromium were increasing in water for this season, so were the levels in *S. aequinoctialis*)). *S. aequinoctialis* samples indicated no significant differences for both seasons when compared to water samples ($p > 0.05$, Appendix 3, Table 7). The concentration of chromium in water and *S. aequinoctialis* at Michiru stream for both seasons was below detection limit. This indicates that chromium levels for the other places could be due to anthropogenic sources. The highest value of chromium at Mudi stream at SRN is attributed to industries. These results showed that the ability of *S. aequinoctialis* accumulating chromium from water cannot be completely ruled out because all water samples indicated chromium below detection limit in the rainy season while it was detected in some algae (*S. aequinoctialis)* samples. The overall results however are different from studies done elsewhere. Chmielewska and Medved (2001) found the mean level of chromium to be 0.008 mg/L in lagoon water situated on the left bank of the river Danube and 1.7 mg/kg

in green algae (*C. glomerata*) sampled in the same water. Black and Mitchel (1952) found the mean level of chromium in seawater collected at Atlantic bridge between Island of Seil and Scotland to be 0.001 mg/L while in brown algae (*F. serratus*) it was 0.14 mg/kg. Pederson and Vaultonburg (1996) found the mean level of chromium sampled in water from Embarras river, Illinois, USA to be in the range 0.005 – 0.006 mg/L while in attached algae it was 31.4 – 66.6 mg/kg.

Table 3.7: Chromium levels in water and algae

Sampling point	Chromium levels in water for rainy season (mg/L)	Chromium levels in water for dry season (mg/L)	Chromium levels in algae for rainy season (mg/kg)	Chromium levels in algae for dry season (mg/kg)
Chirimba stream at Cori	ND	ND	0.087 ± 0.056	0.013 ± 0.001
Chirimba stream at Machinjiri road	ND	ND	0.057 ± 0.023	0.036 ± 0.011
Mudi stream at MDI	ND	ND	0.036 ± 0.002	0.045 ± 0.016
Mudi stream at SRN	ND	0.395 ± 0.085	0.335 ± 0.057	0.663 ± 0.031
Soche WWTP raw sewage	ND	ND	ND	0.024 ± 0.007
Soche WWTP effluent	ND	ND	ND	ND
Blantyre WWTP raw sewage	ND	0.297 ± 0.058	0.431 ± 0.137	0.514 ± 0.003
Blantyre WWTP effluent	ND	0.014 ± 0.013	0.029 ± 0.003	0.035 ± 0.019
Nasolo stream at BNC	ND	0.025 ± 0.004	0.028 ± 0.001	0.075 ± 0.041
Nasolo stream at SRN	ND	0.036 ± 0.011	ND	ND
Michiru stream	ND	ND	ND	ND
Mangunda stream	ND	0.419 ± 0.003	ND	0.153 ± 0.055
Limbe WWTP effluent	ND	ND	ND	0.043 ± 0.012
Limbe WWTP raw sewage	ND	ND	ND	0.061 ± 0.004
Limbe stream at Mpingwe	ND	ND	ND	ND
Limbe stream at Highway	ND	0.037 ± 0.016	ND	ND
Naperi stream at Rainbow paints	ND	ND	ND	0.011 ± 0.002
Naperi stream at Moi road	ND	ND	0.016 ± 0.007	0.063 ± 0.014

MBS chromium drinking water standard (0.05 – 0.1 mg/L)
WHO chromium drinking water standard (0.05mg/L)
Algae data is on dry basis
Values are in the form of mean ± standard deviation

3.1.8 Nickel levels in water and algae

In the rainy season, the range of nickel concentration in water was 0.305 - 0.49 mg/L while in the dry season it was 0.101 - 0.578 mg/L (Table 3.8). Water samples indicated no significant differences for nickel in dry season and rainy season ($p > 0.05$, Appendix 3, Table 8). For both seasons nickel levels in water were higher than MBS (0.05 – 0.15 mg/L) and WHO (0.02 mg/L) drinking water standards. The possible sources of nickel pollution for Blantyre streams are steel industries and waste disposal (Section 2.1.5, Section 2.1.6, Figure 2.2 and Figure 2.3).

In the rainy season, the range of nickel concentration in filamentous green algae (*S. aequinoctialis*) was from below detection limit to 0.443 mg/kg. In the dry season the levels ranged from below detection limit to 0.421 mg/kg (Table 3.8). *S. aequinoctialis* rainy season and dry season nickel levels indicated no significant differences ($p > 0.05$, Appendix 3, Table 8). Water and *S. aequinoctialis* samples nickel levels were not strongly correlated for both seasons ($r = -0.124$ for rainy season (indicating that as the levels of nickel were increasing in water, the levels in *S. aequinoctialis* were decreasing) and $r = 0.496$ for dry season (indicating that as the levels of nickel in water were increasing, so were the levels in *S. aequinoctialis*). Water samples indicated significantly higher nickel levels for rainy season than *S. aequinoctialis* ($p < 0.05$, Appendix 3, Table 8). This was not the case in dry season in which there were no significant differences ($p > 0.05$, Appendix 3, Table 8). High levels of nickel in rainy season for water samples could have come from surface run-off. The concentration of nickel in water for both seasons at Michiru stream was not different from the rest of the places which could be attributed to rocks and deposition. The concentration of nickel in S. aequinoctialis at Michiru stream for both seasons was below detection limit similar to some of the sampling points. The highest value of nickel at Chirimba stream at Cori is attributed to industries since the stream passes through an industrial area. These results did not agree with studies done elsewhere. Chmielewska and Medved (2001) found 0.032 mg/L nickel in lagoon water situated along the left bank of the river Danube and 15.6 mg/kg in green algae (*C. glomerata*) sampled in the same water. Black and Mitchel (1952) found the mean level of nickel in seawater collected at Atlantic bridge between Island of Seil and Scotland to be 0.006 mg/L while in brown algae (*F. serratus*) it was 0.87 mg/kg. Pederson and

Vaultonburg (1996) found the mean level of nickel in water sampled from Embarras river, Illinois, USA to range from below detection limit to 0.02 mg/L while in attached algae it was 24.8 – 72.8 mg/kg.

Table 3.8: Nickel levels in water and algae

Sampling point	Nickel levels in water for rainy season (mg/L)	Nickel levels in water for dry season (mg/L)	Nickel levels in algae for rainy season (mg/kg)	Nickel levels in algae for dry season (mg/kg)
Chirimba stream at Cori	0.398 ± 0.013	0.420 ± 0.009	0.443 ± 0.088	0.028 ± 0.013
Chirimba stream at Machinjiri road	0.391 ± 0.004	0.405 ± 0.004	0.019 ± 0.071	0.416 ± 0.032
Mudi stream at MDI	0.329 ± 0.04	0.349 ± 0.103	0.146 ± 0.003	ND
Mudi stream at SRN	0.347 ± 0.006	0.573 ± 0.034	ND	0.233 ± 0.036
Soche WWTP raw sewage	0.387 ± 0.016	0.234 ± 0.008	ND	0.073 ± 0.012
Soche WWTP effluent	0.392 ± 0.007	0.101 ± 0.003	ND	ND
Blantyre WWTP raw sewage	0.426 ± 0.029	0.505 ± 0.007	ND	0.025 ± 0.002
Blantyre WWTP effluent	0.409 ± 0.030	0.317 ± 0.003	ND	0.016 ± 0.014
Nasolo stream at BNC	0.497 ± 0.007	0.365 ± 0.008	ND	ND
Nasolo stream at SRN	0.451 ± 0.091	0.515 ± 0.110	ND	0.061 ± 0.012
Michiru stream	0.413 ± 0.024	0.113 ± 0.001	ND	ND
Mangunda stream	0.394 ± 0.02	0.578 ± 0.012	ND	0.421 ± 0.026
Limbe WWTP effluent	0.349 ± 0.032	0.236 ± 0.065	ND	0.051 ± 0.013
Limbe WWTP raw sewage	0.305 ± 0.008	0.215 ± 0.035	ND	0.035 ± 0.004
Limbe stream at Mpingwe	0.433 ± 0.044	0.155 ± 0.019	ND	ND
Limbe stream at Highway	0.416 ± 0.012	0.434 ± 0.264	ND	0.063 ± 0.013
Naperi stream at Rainbow paints	0.432 ± 0.009	0.475 ± 0.106	ND	ND
Naperi stream at Moi road	0.405 ± 0.011	0.318 ± 0.004	ND	ND

MBS chromium drinking water standard (0.05 – 0.15 mg/L)
WHO chromium drinking water standard (0.02 mg/L)
Algae data is on dry basis
Values are in the form of mean ± standard deviation

3.2 Heavy metal levels in soils and earthworms

3.2.1 Manganese levels in soils and earthworms

In the rainy season, the range of manganese concentration in soil samples was 10.255 - 17.894 mg/kg while in the dry season it was 8.995 – 31.43 mg/kg (Table 3.9). Soil samples indicated significantly higher manganese levels for dry season than rainy season ($p < 0.05$, Appendix 3, Table 9), which could be due to soil deposition as a result of surface runoff and dilution. All values for both seasons were below the England typical range of the total contents of manganese and related metal ions in soils (200- 2,000 mg/kg, Bohn et.al, 1979). The possible sources of manganese pollution for soils in Blantyre include contaminated stream water, application of pesticides that contain manganese and waste disposal (Section 2.1.5, Section 2.1.6, Figure 2.2 and Figure 2.3).

In the rainy season the range of manganese concentration in earthworms (*Aporrectodea icteria*) was 1.005 - 9.623 mg/kg while in the dry season the range was 1.603 - 7.582 mg/kg (Table 3.9). Comparison of *A. icteria* rainy season and dry season manganese values indicated no significant differences ($p > 0.05$, Appendix 3, Table 9).). Soil and *A. icteria* samples manganese levels were not strongly correlated for both seasons ($r = -0.263$ for rainy season and $r = -0.166$ for dry season (an indication that as manganese levels were increasing in soils for both seasons, in *A. icteria* the levels were decreasing)). Soil samples indicated significantly higher manganese levels for both seasons than *A. icteria* ($p < 0.05$, Appendix 3, Table 9). The levels of manganese in soil and *A. icteria* at Michiru stream in both seasons were not different from most of the sampling points. The possible sources of manganese for soil at Michiru stream are rocks and deposition. The highest level of manganese in *A. icteria* at Limbe WWTP could be as a result of industries. These results are different from studies that were done in Nigeria. Bamgbose et.al (2000) found the mean level of manganese in non-contaminated sites located in Abeokuta, Nigeria to be 10.54 mg/kg for earthworms (*Libyodrilus violaceus*) and 10.41 mg/kg for soils. In the dumpsites the mean level of manganese for *L. violaceus* was 104.51 mg/kg and 113.3 mg/kg for soils. The differences in accumulation of heavy metals between earthworms (*A. icteria*) under this study and results found elsewhere could have come about due to species variations. For example, Morgan and Morris (1982) found that *Dendrobaena rubida* had high concentration of toxic heavy metals than

Lumbricus rubellus living in the same contaminated disused-mine soil. Kamitani and Kaneko (2005) in their study on a floodplain contaminated by heavy metals from an old mine in central Japan found that species belonging to the families Megascolecidae and Lumbricidae had relatively lower concentrations compared to those in Moniligastridae.

Table 3.9: Manganese levels in soils and earthworms

Sampling point	Manganese levels in soils for rainy season (mg/kg)	Manganese levels in soils for dry season (mg/kg)	Manganese levels in earthworms for rainy season (mg/kg)	Manganese levels in earthworms for dry season (mg/kg)
Chirimba stream at Cori	17.894 ± 0.135	12.41 ± 0.883	5.244 ± 2.118	3.309 ± 1.498
Chirimba stream at Machinjiri road	15.700 ± 0.540	10.109 ± 0.333	1.005 ± 0.134	4.655 ± 1.751
Mudi stream at SRN	13.980 ± 0.134	14.813 ± 0.905	2.358 ± 0.282	4.291 ± 2.495
Mudi stream at MDI	10.255 ± 1.033	14.597 ± 0.820	6.387 ± 0.521	4.028 ± 1.686
Michiru stream	10.314 ± 2.92	14.403 ± 0.323	1.945 ± 0.083	2.725 ± 0.484
Naperi stream at Rainbow paints	13.730 ± 0.847	12.853 ± 0.858	3.692 ± 0.384	1.603 ± 0.724
Naperi stream at Moi road	14.146 ± 0.410	13.343 ± 0.344	3.148 ± 1.752	1.881 ± 0.851
Blantyre WWTP	14.181 ± 0.499	27.431 ± 0.949	3.248 ± 0.251	2.078 ± 0.341
Nasolo stream at BNC	10.635 ± 1.050	16.867 ± 0.707	3.014 ± 0.684	4.023 ± 0.269
Nasolo stream at SRN	11.311 ± 1.858	12.013 ± 2.150	2.161 ± 0.129	1.660 ± 0.291
Mangunda Stream	10.955 ± 0.435	8.995 ± 0.180	3.904 ± 1.457	3.831 ± 0.809
Soche WWTP	14.288 ± 0.233	26.783 ± 1.894	4.388 ± 0.574	5.886 ± 0.175
Limbe WWTP	14.502 ± 0.143	31.432 ± 0.355	9.623 ± 0.493	7.582 ± 0.349
Limbe stream at Mpingwe	10.836 ± 1.009	17.427 ± 0.228	7.975 ± 0.582	3.863 ± 0.548
Limbe stream at Highway	12.236 ± 0.329	25.965 ± 1.413	4.194 ± 1.504	1.916 ± 0.227

England typical range of manganese and related metal ions (200- 2,000 mg/kg, Bohn et.al, 1979)
Data is on dry basis
Values are in the form of mean ± standard deviation

3.2.2 Cadmium levels in soils and earthworms

In the rainy season, the range of cadmium concentration in soil samples was from below detection limit to 0.041 mg/kg while in the dry season it was from below detection limit to 0.179 mg/kg (Table 3.10). Comparison of rainy season and dry season soil cadmium levels indicated no significant differences ($p > 0.05$, Appendix 3, Table 10). All rainy season soil samples cadmium values were below the England toxic limit (0.06 mg/kg, Bohn et.al, 1979) and 7% of soil samples were within the England typical range of cadmium and related metal ions (0.01- 7 mg/kg, Bohn et.al, 1979) with the rest lower

than the values for other countries (Romanian soil cadmium maximum allowable limit is 3 mg/kg, Lacatusu et.al 1999; Netherlands soil cadmium target value is 0.8 mg/kg, the target value is defined as the concentration that ought to be aimed for in the long term. This value is based on a standard soil, which is defined as that soil which has 10% organic matter and 25% clay, Alloway and Ayres, 1997, Alloway, 1996; In Canada the normal background level of cadmium in soils is 0.5 mg/kg, Alloway and Ayres, 1997). In dry season 33% of the soil samples were above the England toxic limit, 67% were within the England range and all the values were below the Canadian, Netherlands and Romanian values. The possible sources of cadmium pollution for Blantyre soils are waste disposal, coal combustion, iron and steel production, vehicle emissions and phosphate fertilizer manufacture and use (Section 2.1.5, Section 2.1.6, Figure 2.2 and Figure 2.3).

In the rainy season, the range of cadmium concentration in earthworms (*A. icteria*) was 0.108 - 0.144 mg/kg while in the dry season it was 0.115 - 0.551 mg/kg (Table 3.10). *A. icteria* samples indicated significantly higher cadmium levels in dry season than rainy season ($p < 0.05$, Appendix 3, Table 10). Soil and *A. icteria* samples cadmium levels were not strongly correlated for both seasons ($r = -0.033$ for rainy season (an indication that as cadmium levels were decreasing in soils, in *A. icteria* they were increasing) and $r = 0.092$ for dry season (indicating that as cadmium levels were increasing in soils, so were the levels in *A. icteria*). *A. icteria* indicated significantly higher cadmium levels for both seasons as compared to soil samples ($p < 0.05$, Appendix 3, Table 10). In both seasons the level of cadmium at Michiru stream in water samples was below detection limit with that in *A. icteria* among the lowest. This indicated that the possible sources of cadmium in soils for the other areas are anthropogenic. The possible sources of cadmium at Michiru include deposition and rocks. The possible source for the highest level of cadmium in *A. icteria* at Limbe WWTP is from industries. These results agreed with studies done in Nigeria. Bamgbose et.al (2000) found the mean levels of cadmium in non-contaminated sites located in Abeokuta, Nigeria to be 0.80 mg/kg for earthworms (*L. violaceus*) and 0.81 mg/kg for soils. In the dumpsites the mean level of cadmium for *L. violaceus* was 5.46 mg/kg while in soils it was 4.51mg/kg.

Table 3.10: Cadmium levels in soils and earthworms

Sampling point	Cadmium levels in soils for rainy season (mg/kg)	Cadmium levels in soils for dry season (mg/kg)	Cadmium levels in earthworms for rainy season (mg/kg)	Cadmium levels in earthworms for dry season (mg/kg)
Chirimba stream at Cori	0.0413 ± 0.051	0.014 ± 0.004	0.123 ± 0.012	0.169 ± 0.035
Chirimba stream at Machinjiri road	ND	0.015 ± 0.001	0.128 ± 0.016	0.287 ± 0.011
Mudi stream at SRN	ND	0.161 ± 0.041	0.144 ± 0.002	0.429 ± 0.026
Mudi stream at MDI	ND	0.067 ± 0.011	0.136 ± 0.007	0.174 ± 0.005
Michiru stream	ND	ND	0.115 ± 0.004	0.144 ± 0.046
Naperi stream at Rainbow paints	ND	0.034 ± 0.002	0.108 ± 0.014	0.115 ± 0.051
Naperi stream at Moi road	ND	ND	0.123 ± 0.013	0.219 ± 0.093
Blantyre WWTP	ND	0.134 ± 0.048	0.118 ± 0.006	0.170 ± 0.019
Nasolo stream at BNC	ND	ND	0.119 ± 0.002	0.185 ± 0.023
Nasolo stream at SRN	ND	ND	0.129 ± 0.003	0.502 ± 0.014
Mangunda Stream	ND	0.132 ± 0.033	0.121 ± 0.004	0.239 ± 0.053
Soche WWTP	ND	0.042 ± 0.028	0.114 ± 0.010	0.329 ± 0.012
Limbe WWTP	ND	0.179 ± 0.019	0.127 ± 0.019	0.551 ± 0.018
Limbe stream at Mpingwe	ND	ND	0.109 ± 0.013	0.117 ± 0.026
Limbe stream at Highway	ND	0.024 ± 0.011	0.114 ± 0.009	0.188 ± 0.121

England typical range of cadmium and related metal ions (0.01- 7 mg/kg, Bohn et.al, 1979)
England cadmium toxic limit (0.06 mg/kg, Bohn et.al, 1979)
Maximum cadmium allowable limit for Romanian soils (3 mg/kg, Lacatusu et.al 1999)
Netherlands soil cadmium target value (0.8 mg/kg, Alloway and Ayres, 1997, Alloway, 1996)
Canadian normal background levels of cadmium in soils (0.5 mg/kg, Alloway and Ayres, 1997)
Data is on dry basis
Values are in the form of mean ± standard deviation

3.2.3 Copper levels in soils and earthworms

In the rainy season, the range of copper concentration in soils was 0.130 – 5.870 mg/kg while in the dry season it was 0.119 - 10.134 mg/kg (Table 3.11). Comparison of rainy season and dry season soil copper values indicated no significant differences ($p > 0.05$, Appendix 3, Table 11). Except for Mangunda stream (where the possible source of copper is run-off from the dumpsite) in rainy season, all values agreed with studies done by Saka and Ambali (1999) who found copper levels to be less than 10 mg/kg dry soil in middle and lower Shire River, Malawi. In the rainy season 20% of the soil samples had copper values within the England typical range of the total contents of copper and related metal ions (2- 100 mg/kg, Bohn et.al, 1979) with none of the values within the Canadian

normal background level of copper (30 mg/kg, Alloway and Ayres, 1997), Netherlands target value of copper (36 mg/kg, Alloway and Ayres, 1997; Alloway, 1996) and Romanian maximum allowable limit of copper in soils (100 mg/kg, Lacatusu et.al 1999). In the dry season 40% of the copper values were within the England range with none of the values falling for the Netherlands, Canadian and Romanian values. The possible sources of copper pollution for Blantyre soils are metal processing industries and waste disposal (Section 2.1.5, Section 2.1.6, Figure 2.2 and Figure 2.3).

In the rainy season, the range of copper concentration in earthworms (*A. icteria*) was from below detection limit to 0.413 mg/kg while in the dry season it was 0.005 - 0.373 mg/kg (Table 3.11). *A. icteria* copper values for rainy season and dry season indicated no significant differences ($p > 0.05$, Appendix 3, Table 11). Soil and *A. icteria* samples copper levels were not strongly correlated for both seasons ($r = -0.036$ for rainy season and $r = -0.260$ for dry season (an indication that as copper levels were increasing in soils for both seasons, in *A. icteria* they were decreasing)). Soil samples indicated significantly higher copper values for both seasons when compared to *A. icteria* ($p < 0.05$, Appendix 3, Table 11). The concentration of copper at Michiru stream in soil and *A. icteria* for both seasons was among the lowest values. This suggested that the possible sources of copper for the other areas are anthropogenic. The possible sources of copper for Michiru stream are deposition and rocks. The possible source for the highest level of copper in *A. icteria* at Blantyre WWTP is from industries. These results were different from studies that were done in Nigeria, possibly due to species variations. Bamgbose et.al (2000) found the mean levels of copper in non-contaminated sites located in Abeokuta, Nigeria to be 1.03 mg/kg for earthworms, *L. violaceus* and 1.60 mg/kg for soils. In the dumpsites the level was 31.02mg/kg in *L. violaceus* while in soils 36.59 mg/kg.

Table 3.11: Copper levels in soils and earthworms

Sampling point	Copper levels in soils for rainy season (mg/kg)	Copper levels in soils for dry season (mg/kg)	Copper levels in earthworms for rainy season (mg/kg)	Copper levels in earthworms for dry season (mg/kg)
Chirimba stream at Cori	1.690 ± 0.136	0.735 ± 0.136	0.169 ± 0.163	0.073 ± 0.062
Chirimba stream at Machinjiri road	1.622 ± 0.401	1.632 ± 0.044	ND	0.139 ± 0.043
Mudi stream at SRN	3.353 ± 0.841	1.305 ± 0.162	0.141 ± 0.065	0.352 ± 0.026
Mudi stream at MDI	0.896 ± 0.054	7.311 ± 2.315	0.189 ± 0.049	0.235 ± 0.089
Michiru stream	0.413 ± 0.219	2.469 ± 0.454	ND	0.005 ± 0.002
Naperi stream at Rainbow paints	1.479 ± 0.356	7.114 ± 1.424	0.004 ± 0.001	0.128 ± 0.013
Naperi stream at Moi road	1.899 ± 0.157	3.281 ± 0.972	0.040 ± 0.009	0.099 ± 0.027
Blantyre WWTP	5.870 ± 0.858	0.899 ± 0.054	0.413 ± 0.223	0.202 ± 0.002
Nasolo stream at BNC	0.754 ± 0.167	1.706 ± 0.471	0.051 ± 0.011	0.373 ± 0.065
Nasolo stream at SRN	1.186 ± 0.151	0.313 ± 0.026	0.032 ± 0.005	0.136 ± 0.004
Mangunda Stream	0.130 ± 0.027	10.134 ± 0.975	ND	0.281 ± 0.041
Soche WWTP	3.177 ± 0.126	3.017 ± 0.397	0.094 ± 0.068	0.044 ± 0.003
Limbe WWTP	1.666 ± 0.150	0.549 ± 0.067	0.214 ± 0.157	0.265 ± 0.119
Limbe stream at Mpingwe	0.350 ± 0.060	0.119 ± 1.114	0.026 ± 0.014	0.028 ± 0.006
Limbe stream at Highway	1.158 ± 0.218	1.036 ± 0.006	0.109 ± 0.039	0.155 ± 0.012

England typical range of copper and related metal ions (2- 100 mg/kg, Bohn et.al, 1979)
Maximum copper allowable limit for Romanian soils (100 mg/kg, Lacatusu et.al 1999)
Netherlands soil copper target value (36 mg/kg, Alloway and Ayres, 1997; Alloway, 1996)
Canadian normal background levels of copper in soils (30 mg/kg, Alloway and Ayres, 1997)
Data is on dry basis
Values are in the form of mean ± standard deviation

3.2.4 Iron levels in soils and earthworms

In the rainy season, the range of iron concentration in soil samples was 61.283 - 67.560 mg/kg while in the dry season it was 11.827 - 82.824 mg/kg (Table 3.12). Soil samples indicated significantly higher iron levels in dry season than in rainy season ($p < 0.05$, Appendix 3, Table 12). This could be due to soil deposition as a result of runoff and dilution. All values for both seasons were less than the England typical range of the total contents of iron and related metal ions in soils (50,000- 300,000 mg/kg, Bohn et.al, 1979). The possible sources of iron pollution for Blantyre soils are corrosion of metals, electricity generation, iron and steel industries, chemical and electronic industries and waste disposal (Section 2.1.5, Section 2.1.6, Figure 2.2 and Figure 2.3).

In the rainy season, the range of iron concentration in earthworms (A. *icteria*) was 16.59 - 54.82 mg/kg while in the dry season it was 13.697 - 63.727 mg/kg (Table 3.12). *A. icteria* samples indicated significantly higher levels of iron in dry season than rainy season ($p < 0.05$, Appendix 3, Table 12). Soil and *A. icteria* samples iron levels were not strongly correlated for both seasons ($r = 0.098$ for rainy season (an indication that as iron levels were increasing in soils, so were the levels in *A. icteria*) and $r = -0.271$ for dry season (an indication that as iron levels were increasing in soils, in *A. icteria* the levels were decreasing)). Soil samples indicated significantly higher iron levels for both seasons as compared to *A. icteria* ($p < 0.05$, Appendix 3, Table 12). The concentration of iron in soils and *A. icteria* for both seasons at Michiru stream was not different from most of the sampling points. The possible sources of iron for Michiru stream are rocks and deposition. The possible source for the highest level of iron in *A. icteria* at Mudi stream at SRN is from industries. These results indicated that *A. icteria* does not accumulate iron.

Table 3.12: Iron levels in soils and earthworms

Sampling point	Iron levels in soils for rainy season (mg/kg)	Iron levels in soils for dry season (mg/kg)	Iron levels in earthworms for rainy season (mg/kg)	Iron levels in earthworms for dry season (mg/kg)
Chirimba stream at Cori	65.710 ± 0.439	12.698 ± 0.534	49.083 ± 3.24	30.843 ± 1.816
Chirimba stream at Machinjiri road	63.873 ± 2.500	51.136 ± 0.061	16.59 ± 5.430	33.833 ± 0.376
Mudi stream at SRN	67.560 ± 0.104	28.524 ± 0.083	45.533 ± 0.514	63.727 ± 2.581
Mudi stream at MDI	66.347 ± 0.602	48.615 ± 0.191	51.743 ± 2.187	34.473 ± 0.232
Michiru stream	65.680 ± 0.509	54.851 ± 0.489	43.827 ± 4.917	37.743 ± 0.025
Naperi stream at Rainbow paints	67.203 ± 1.501	64.495 ± 0.014	40.953 ± 2.820	22.863 ± 1.272
Naperi stream at Moi road	67.280 ± 0.195	82.824 ± 0.517	40.157 ± 4.925	13.697 ± 0.079
Blantyre WWTP	63.267 ± 5.860	34.841 ± 0.513	39.51 ± 3.676	16.407 ± 1.554
Nasolo stream at BNC	63.707 ± 1.099	42.001 ± 2.016	47.243 ± 2.069	21.012 ± 0.827
Nasolo stream at SRN	62.790 ± 4.525	54.509 ± 1.079	51.257 ± 0.875	40.303 ± 1.912
Mangunda Stream	63.643 ± 0.333	43.478 ± 0.903	52.89 ± 1.119	34.043 ± 0.812
Soche WWTP	66.110 ± 0.318	64.110 ± 0.587	47.587 ± 5.711	44.951 ± 1.745
Limbe WWTP	67.453 ± 0.191	52.762 ± 1.031	48.527 ± 1.720	55.413 ± 0.501
Limbe stream at Mpingwe	61.283 ± 3.472	11.827 ± 1.043	44.043 ± 2.42	42.697 ± 0.309
Limbe stream at Highway	65.250 ± 1.788	27.854 ± 1.204	54.82 ± 0.506	36.037 ± 1.972

England typical range of copper and related metal ions (50,000- 300,000 mg/kg, Bohn et.al, 1979)
Data is on dry basis
Values are in the form of mean ± standard deviation

3.2.5 Zinc levels in soils and earthworms

In the rainy season, the range of zinc concentration in soils was 1.372 - 17.45 mg/kg while in the dry season it was 0.255 – 14.463 mg/kg (Table 3.13). Comparison of dry season and rainy season soil samples zinc levels indicated no significant differences ($p > 0.05$, Appendix 3, Table 13). These values were lower than those found by Saka and Ambali (1999) who found that zinc varied from 35.4 ± 8.4 – 202.5 ± 18.2 mg/kg dry soil, in the middle and lower Shire River, Malawi. For both seasons, all the values were below the England zinc toxic limit (50 mg/kg, Bohn et.al, 1979), Canadian normal background zinc level (60 mg/kg, Alloway and Ayres, 1997; Alloway, 1996), Netherlands target value of zinc (140 mg/kg, Alloway and Ayres, 1997; Alloway, 1996) and Romanian zinc limit in soils (300 mg/kg, Lacatusu et.al 1999). In the rainy season 27% of the values were within the England range of zinc and related metal ions (10- 300 mg/kg, Bohn et.al, 1979) while in the dry season it was 7%. The possible sources of zinc pollution for soils

in Blantyre are metal processing industries and waste disposal (Section 2.1.5, Section 2.1.6, Figure 2.2 and Figure 2.3).

In the rainy season, the range of zinc concentration in earthworms (*A. icteria*) was 0.664 - 5.274 mg/kg while in the dry season it was 0.461 - 5.109 mg/kg (Table 3.13). In comparing the rainy season and dry season values, there were significant differences ($p < 0.05$, Appendix 3, Table 13). Soil and *A. icteria* samples zinc levels were not strongly correlated for both seasons ($r = 0.235$ for rainy season and $r = 0.161$ for dry season (an indication that as zinc levels were increasing in soils for both seasons, so were the levels in *A. icteria*)). Soil samples indicated significantly higher levels of zinc than *A. icteria* in the rainy season ($p < 0.05$, Appendix 3, Table 13) while in the dry season there were no significant differences ($p > 0.05$, Appendix 3, Table 13). The levels of zinc in soils at Michiru stream for both seasons were lower than most of the sampling points (indicating anthropogenic sources being the cause of higher zinc levels in the other sampling areas) while those in *A. icteria* were not different from most of the sampling points. The possible sources of zinc for Michiru stream are rocks and deposition. The possible source for the highest level of zinc in *A. icteria* for Soche WWTP is domestic wastewater. These results only agreed with studies done at Nigerian dumpsites where zinc levels were higher in soils than earthworms. The difference in levels between *A. icteria* and *L. violaceus* for non-contaminated sites is possibly due to species variations. Bamgbose et.al (2000) found the mean level of zinc in non-contaminated sites located in Abeokuta, Nigeria to be 7.02 mg/kg for earthworms (*L. violaceus*) and 6.74 mg/kg for soils. In dumpsites the mean level was 116.38 mg/kg for *L. violaceus* while in soils 131.71 mg/kg.

Table 3.13: Zinc levels in soils and earthworms

Sampling point	Zinc levels in soils for rainy season (mg/kg)	Zinc levels in soils for dry season (mg/kg)	Zinc levels in earthworms for rainy season (mg/kg)	Zinc levels in earthworms for dry season (mg/kg)
Chirimba stream at Cori	5.032 ± 0.239	3.151 ± 0.441	3.671 ± 1.316	4.298 ± 0.081
Chirimba stream at Machinjiri road	9.538 ± 0.511	3.173 ± 0.486	3.43 ± 0.266	1.262 ± 1.007
Mudi stream at SRN	13.94 ± 0.832	5.219 ± 0.534	4.082 ± 0.767	0.695 ± 0.261
Mudi stream at MDI	5.174 ± 0.369	0.255 ± 0.201	3.713 ± 0.308	2.129 ± 0.109
Michiru stream	3.311 ± 0.302	3.274 ± 0.995	3.004 ± 0.170	1.821 ± 0.139
Naperi stream at Rainbow paints	5.519 ± 1.085	2.162 ± 0.591	4.026 ± 0.255	0.702 ± 0.271
Naperi stream at Moi road	6.290 ± 0.191	1.567 ± 0.499	3.160 ± 2.385	0.741 ± 0.196
Blantyre WWTP	17.453 ± 0.923	3.215 ± 0.518	4.820 ± 0.740	4.292 ± 0.106
Nasolo stream at BNC	7.652 ± 1.837	6.263 ± 1.301	4.352 ± 0.791	1.895 ± 1.051
Nasolo stream at SRN	11.087 ± 0.214	7.038 ± 1.564	2.777 ± 0.235	1.148 ± 0.081
Mangunda Stream	1.372 ± 0.085	1.436 ± 0.554	0.664 ± 0.115	5.109 ± 0.923
Soche WWTP	16.177 ± 0.445	14.463 ± 0.644	5.274 ± 0.681	4.055 ± 0.039
Limbe WWTP	3.829 ± 0.639	2.145 ± 0.023	2.707 ± 0.259	1.395 ± 0.315
Limbe stream at Mpingwe	2.411 ± 0.295	2.578 ± 0.154	2.777 ± 0.273	1.506 ± 0.578
Limbe stream at Highway	7.610 ± 0.515	6.051 ± 0.046	3.983 ± 1.659	4.453 ± 0.442

England typical range of zinc and related metal ions (10- 300 mg/kg, Bohn et.al, 1979)
England zinc toxic limit (50 mg/kg, Bohn et.al, 1979)
Maximum zinc allowable limit for Romanian soils (300 mg/kg, Lacatusu et.al 1999)
Netherlands soil zinc target value (140 mg/kg, Alloway and Ayres, 1997; Alloway, 1996)
Canadian normal background levels of zinc in soils (60 mg/kg, Alloway and Ayres, 1997; Alloway, 1996)
Data is on dry basis
Values are in the form of mean ± standard deviation

3.2.6 Lead levels in soils and earthworms

In the rainy season, the range of lead concentration in soils was 0.512 - 2.945 mg/kg while in the dry season it was 0.031 - 3.485 mg/kg (Table 3.14). In comparing the rainy and dry season values, there were no significant differences ($p > 0.05$, Appendix 3, Table 14). All values agreed with studies done by Saka and Ambali (1999) who found lead levels to be less than 10 mg/kg dry soil in middle and lower Shire River, Malawi. Most of the values were lower than the levels for other countries (In England natural soil lead concentration that has been implicated as being toxic is 10 mg/kg, Bohn et.al, 1979; Netherlands soil lead target value is 85 mg/kg and Canada's normal background level of lead is 25 mg/kg, Alloway and Ayres, 1997; Alloway, 1996 ; Romanian maximum soil

lead allowable limit is 100 mg/kg, Lacatusu et.al, 1999) except for the England typical range of lead and typical metal ions (2 – 200 mg/kg, Bohn et.al, 1979) whereby 33% in the rainy season and 27% in the dry season fell within this range. The possible sources of lead pollution for Blantyre soils are industrial wastes, sewage sludge if used as a fertilizer and vehicles emissions (Section 2.1.5, Section 2.1.6, Figure 2.2 and Figure 2.3).

In the rainy season, the range of lead in earthworms (*A. icteria*) was from below detection limit to 0.796 mg/kg while in the dry season it was from below detection limit to 0.476 mg/kg (Table 3.14). In comparing rainy season and dry season lead levels in *A. icteria*, there were no significant differences ($p > 0.05$, Appendix 3, Table 14). Soil and *A. icteria* samples lead levels were strongly correlated in the dry season than rainy season ($r = 0.195$ for rainy season and $r = 0.558$ for dry season (an indication that as lead levels were increasing in soils for both seasons, so were the levels in *A. icteria*). Soil samples indicated significantly higher lead levels in both seasons when compared to *A. icteria* ($p < 0.05$, Appendix 3, Table 14). The concentration of lead in soils for Michiru stream for both seasons was not different from most of the sampling points while that in *A. icteria* was below detection limit (suggesting a possibility of pollution by anthropogenic sources for the other areas). The possible sources of lead for Michiru stream soils are deposition and rocks. The possible source for the highest levels of lead in *A. icteria* at Nasolo stream at BNC is vehicle emissions. These results agreed with studies done at Nigerian dumpsites and not at non-contaminated sites. This could possibly be due to species variations. Bamgbose et.al (2000) found the mean levels of lead in non-contaminated sites located in Abeokuta, Nigeria to be 5.04 mg/kg for earthworms (*L. violaceus*) and 4.94 mg/kg for soils. In dumpsites the mean levels were 160.83 mg/kg for *L. violaceus* and 185.06 mg/kg for soils.

Table 3.14: Lead levels in soils and earthworms

Sampling point	Lead levels in soils for rainy season (mg/kg)	Lead levels in soils for dry season (mg/kg)	Lead levels in earthworms for rainy season (mg/kg)	Lead levels in earthworms for dry season (mg/kg)
Chirimba stream at Cori	0.553 ± 0.011	1.379 ± 0.251	0.135 ± 0.024	0.421 ± 0.150
Chirimba stream at Machinjiri road	1.416 ± 0.271	2.476 ± 0.311	0.114 ± 0.001	0.270 ± 0.024
Mudi stream at SRN	2.436 ± 0.408	3.485 ± 0.671	0.336 ± 0.028	0.042 ± 0.028
Mudi stream at MDI	2.945 ± 0.883	1.754 ± 0.435	ND	0.190 ± 0.01
Michiru stream	2.321 ± 0.371	0.031 ± 0.176	ND	ND
Naperi stream at Rainbow paints	1.841 ± 0.260	0.215 ± 0.089	ND	0.025 ± 0.106
Naperi stream at Moi road	1.765 ± 0.187	2.259 ± 0.314	ND	ND
Blantyre WWTP	2.462 ± 0.233	3.043 ± 0.092	ND	0.077 ± 0.009
Nasolo stream at BNC	1.965 ± 0.204	0.308 ± 0.254	0.796 ± 0.176	0.445 ± 0.137
Nasolo stream at SRN	1.611 ± 0.307	0.041 ± 0.147	0.482 ± 0.331	0.182 ± 0.015
Mangunda Stream	0.512 ± 0.135	0.706 ± 0.091	ND	0.476 ± 0.059
Soche WWTP	1.468 ± 0.039	1.167 ± 0.178	ND	0.342 ± 0.049
Limbe WWTP	1.161 ± 0.233	0.411 ± 0.195	ND	0.135 ± 0.029
Limbe stream at Mpingwe	0.818 ± 0.053	0.636 ± 0.081	ND	0.016 ± 0.011
Limbe stream at Highway	2.059 ± 0.388	1.146 ± 0.124	ND	0.297 ± 0.023

England typical range of lead and related metal ions (2 – 200 mg/kg, Bohn et.al, 1979)
England lead toxic limit (10 mg/kg, Bohn et.al, 1979)
Maximum lead allowable limit for Romanian soils (100 mg/kg, Lacatusu et.al, 1999)
Netherlands soil lead target value (85 mg/kg, Alloway and Ayres, 1997; Alloway, 1996)
Canadian normal background levels of lead in soils (25 mg/kg, Alloway and Ayres, 1997; Alloway, 1996)
Data is on dry basis
Values are in the form of mean ± standard deviation

3.2.7 Chromium levels in soils and earthworms

In the rainy season, the range of chromium concentration in soils was from below detection limit to 6.832 mg/kg while in the dry season 0.053 - 8.191 mg/kg (Table 3.15). In comparing the rainy season and dry season soil results, there were no significant differences ($p > 0.05$, Appendix 3, Table 15). All values agreed with studies done by Saka and Ambali (1999) who found chromium levels to be less than 10 mg/kg dry soil in middle and lower Shire River, Malawi. All chromium values were below the England toxic limit (20 mg/kg, Bohn et.al, 1979) and Netherlands target value (100 mg/kg, Alloway and Ayres, 1997; Alloway, 1996). In the rainy season 27% of the soil samples were above the Canadian normal background value for chromium (2.5 mg/kg, Alloway and Ayres, 1997; Alloway, 1996) and 7% were within England typical range for

chromium and related metal ions (5 – 1,000mg/kg, Bohn et.al, 1979). In the dry season 27% of the soil samples were above the Canadian normal background value for chromium and 13% were within England typical range for chromium and related metal ions. The possible sources of chromium pollution for Blantyre soils are coal combustion, industrial waste disposal and sewage sludge if used as a fertilizer (Section 2.1.5, Section 2.1.6, Figure 2.2 and Figure 2.3).

In the rainy season, all the sampling points indicated earthworms (*A. icteria*) chromium concentration to be below detection limit while in the dry season, the range was from below detection limit to 0.031 mg/kg (Table 3.15). Only 33% of the dry season *A. icteria* samples indicated chromium values above detection limit. *A. icteria* samples dry season chromium levels were significantly higher than those of rainy season ($p < 0.05$, Appendix 3, Table 15). Soil and *A. icteria* samples correlation coefficient for rainy season could not be computed since all *A. icteria* samples indicated chromium levels below detection limit while in the dry season the samples were not strongly correlated ($r = -0.190$ (an indication that as the levels of chromium in soils were increasing, in *A. icteria* the levels were decreasing)). Soil samples indicated significantly higher chromium levels for both seasons when compared to *A. icteria* samples ($p < 0.05$, Appendix 3, Table 15). The levels of chromium in soils and A. icteria at Michiru stream for both seasons were not different from most of the sampling points. The possible sources of chromium at Michiru stream are rocks and deposition. The possible source for the highest level of chromium in A. icteria at Mangunda stream is the dumpsite. These results did not agree with studies done in Nigeria possibly due to species variations. Bamgbose et.al (2000) found the mean levels of chromium in non-contaminated sites located in Abeokuta, Nigeria to be 0.55 mg/kg for earthworms (*L. violaceus*) and 0.49 mg/kg for soils. In dumpsites the mean level was 9.64 mg/kg for *L. violaceus* while in soils the level was 8.40 mg/kg.

Table 3.15: Chromium levels in soils and earthworms

Sampling point	Chromium levels in soils for rainy season (mg/kg)	Chromium levels in soils for dry season (mg/kg)	Chromium levels in earthworms for rainy season (mg/kg)	Chromium levels in earthworms for dry season (mg/kg)
Chirimba stream at Cori	1.240 ± 0.351	0.491 ± 0.021	ND	ND
Chirimba stream at Machinjiri road	1.283 ± 0.285	0.151 ± 1.056	ND	ND
Mudi stream at SRN	4.423 ± 0.132	5.618 ± 1.087	ND	0.018 ± 0.003
Mudi stream at MDI	2.371 ± 0.922	0.932 ± 0.057	ND	ND
Michiru stream	2.603 ± 0.558	1.085 ± 0.154	ND	ND
Naperi stream at Rainbow paints	2.847 ± 1.237	2.813 ± 0.294	ND	0.008 ± 0.001
Naperi stream at Moi road	1.798 ± 0.423	1.345 ± 0.301	ND	ND
Blantyre WWTP	6.832 ± 1.673	8.191 ± 0.704	ND	0.029 ± 0.012
Nasolo stream at BNC	0.534 ± 0.157	1.993 ± 1.508	ND	ND
Nasolo stream at SRN	0.537 ± 0.468	0.053 ± 0.027	ND	ND
Mangunda Stream	ND	3.484 ± 0.584	ND	0.031 ± 0.018
Soche WWTP	1.632 ± 0.224	1.913 ± 0.814	ND	0.014 ± 0.006
Limbe WWTP	1.192 ± 0.159	0.205 ± 0.094	ND	ND
Limbe stream at Mpingwe	0.367 ± 0.542	0.069 ± 0.147	ND	ND
Limbe stream at Highway	1.374 ± 0.723	0.274 ± 0.063	ND	ND

England typical range of chromium and related metal ions (5 – 1,000mg/kg, Bohn et.al, 1979)
England chromium toxic limit (20 mg/kg, Bohn et.al, 1979)
Netherlands soil chromium target value (100 mg/kg, Alloway and Ayres, 1997; Alloway, 1996)
Canadian normal background levels of chromium in soils (2.5 mg/kg, Alloway and Ayres, 1997; Alloway, 1996)
Data is on dry basis
Values are in the form of mean ± standard deviation

3.2.8 Nickel levels in soils and earthworms

In the rainy season, the range of nickel concentration in soil samples was from below detection limit to 2.891 mg/kg while in the dry season it was 0.026 - 4.319 mg/kg (Table 3.16). In comparing the rainy season and dry season soil nickel levels, there was no significant difference ($p > 0.05$, Appendix 3, Table 16). All the nickel values in soils were below the recommended values for other countries (Netherlands target value for nickel in soils is 35 mg/kg while in Canada the normal background level of nickel in soils is 20 mg/kg ,Alloway And Ayres, 1997; Alloway, 1996; England typical range of total

contents of nickel and related metal ions in soils is 10- 1000 mg/kg and natural soil concentration of nickel that has been implicated as being toxic is 40 mg/kg, Bohn et.al, 1979), however Lenntech (2006) talks about the nickel content of a soil as being as low as 0.2 mg/kg or as high as 450 mg/kg in some clay and loamy soils whereby 87% of soil samples in the rainy season and 80% in the dry fell within this range. The possible sources of nickel pollution for Blantyre soils are corrosion of metals, electricity generation, metal processing industries, chemical and electronic industries and waste disposal (Section 2.1.6, Figure 2.2 and Figure 2.3).

In the rainy season, the range of nickel in earthworms (*A. icteria*) was 0.291- 0.869 mg/kg while in the dry season it was 0.043- 0.93 mg/kg (Table 3.16). In comparing rainy season and dry season *A. icteria* nickel levels, there was no significant difference ($p > 0.05$, Appendix 3, Table 16). Soil and *A. icteria* samples nickel levels for both seasons were not strongly correlated ($r = 0.191$ for rainy season (an indication that as the levels of nickel in soils increased, so were the levels in *A. icteria*) and $r = -0.193$ for dry season (indicating that as the levels of nickel in soils were increasing, the levels in *A. icteria* were decreasing)). In comparing soil nickel levels to those found in *A. icteria* for both seasons, there was no significant difference ($p > 0.05$, Appendix 3, Table 16). The levels of nickel in soil samples at Michiru stream for both seasons were not different from most of the sampling points. The possible sources of nickel for soils at Michiru stream are rocks and deposition. The possible source for the highest level of nickel in A. icteria at Chirimba stream at Machinjiri road is industries. These results indicated that A. *icteria* does not accumulate nickel from soils.

Table 3.16: Nickel levels in soils and earthworms

Sampling point	Nickel levels in soils for rainy season (mg/kg)	Nickel levels in soils for dry season (mg/kg)	Nickel levels in earthworms for rainy season (mg/kg)	Nickel levels in earthworms for dry season (mg/kg)
Chirimba stream at Cori	0.001 ± 0.001	0.642 ± 0.071	0.639 ± 0.123	0.449 ± 0.038
Chirimba stream at Machinjiri road	1.518 ± 0.182	0.443 ± 0.231	0.295 ± 0.094	0.93 ± 0.02
Mudi stream at SRN	2.530 ± 0.183	2.942 ± 0.861	0.382 ± 0.057	0.743 ± 0.032
Mudi stream at MDI	0.928 ± 0.339	0.052 ± 0.012	0.526 ± 0.168	0.128 ± 0.011
Michiru stream	2.891 ± 0.519	1.451 ± 0.374	0.367 ± 0.018	0.043 ± 0.024
Naperi stream at Rainbow paints	2.455 ± 0.651	0.856 ± 0.105	0.38 ± 0.020	0.350 ± 0.045
Naperi stream at Moi road	1.090 ± 0.245	4.319 ± 0.562	0.334 ± 0.081	0.255 ± 0.041
Blantyre WWTP	1.146 ± 0.192	2.543 ± 0.463	0.324 ± 0.036	0.542 ± 0.048
Nasolo stream at BNC	0.410 ± 0.126	0.074 ± 0.115	0.297 ± 0.055	0.249 ± 0.039
Nasolo stream at SRN	0.930 ± 0.119	0.968 ± 0.141	0.325 ± 0.029	0.652 ± 0.031
Mangunda Stream	ND	4.141 ± 0.374	0.291 ± 0.026	0.459 ± 0.037
Soche WWTP	0.801 ± 0.165	1.191 ± 0.072	0.869 ± 0.440	0.357 ± 0.042
Limbe WWTP	1.400 ± 0.113	0.556 ± 0.142	0.495 ± 0.028	0.272 ± 0.024
Limbe stream at Mpingwe	0.264 ± 0.056	1.817 ± 0.176	0.353 ± 0.031	0.047 ± 0.043
Limbe stream at Highway	0.588 ± 0.164	0.026 ± 0.014	0.283 ± 0.066	0.842 ± 0.048

England typical range of nickel and related metal ions (10- 1000mg/kg, Bohn et.al, 1979)
England nickel toxic limit (40mg/kg, Bohn et.al, 1979)
Netherlands soil nickel target value (35mg/kg, Alloway and Ayres, 1997; Alloway, 1996)
Canadian normal background levels of nickel in soils (20mg/kg, Alloway and Ayres, 1997; Alloway, 1996)
Data is on dry basis
Values are in the form of mean ± standard deviation

3.2.9 Correlation of algae and soils

Correlations were done for algae (*S. aequinoctialis*) and soils for both seasons. This was done in order to determine whether *S. aequinoctialis* can be used as an indicator for general heavy metal pollution since it showed the ability to accumulate certain heavy metals (Sections 3.1.1 to 3.1.8). The following were the correlations (metal (rainy season, dry season)); manganese (0.077, 0.292), cadmium (0.180, 0.009), copper (0.185, 0.250), iron (-0.184, 0.300), zinc (-0.452, 0.480), lead (-0.146, -0.427), chromium (0.356, 0.397) and nickel (0.356, 0.155). The heavy metals levels were not strongly correlated however in considering both seasons, 67% of the levels were positively correlated and 33% of the

levels were negatively correlated. This means that algae (*S. aequinoctialis*) can be used as a biological indicator of heavy metal pollution.

3.3 Organic matter

3.3.1 Organic matter levels in soils

In the rainy season, the range of organic matter for soil samples was 0.588 – 9.266% while in the dry season it was 0.559 – 9.357% (Figure 3.1). In comparing the rainy season and dry season values, there were no significant differences ($p > 0.05$, Appendix 3, Table 17). The organic matter content of 47% of the sampling points in the rainy season and 40% of the sampling points in the dry season was within the range of a representative mineral soil (about 3 - 5%). This means that this percentage of soil samples had high capacity of binding heavy metals (Section 1.4.1). The organic matter content at Michiru stream was among the lowest for both seasons, which could mostly be attributed to its terrain which encourages surface run-off. The highest level of organic matter at Mangunda stream in dry season could be as result of deposition due to surface run-off from the dumpsite. The possible source for high levels of organic matter in both seasons at Blantyre WWTP is industries. These results were different from studies done in Nigeria. Bamgbose et.al (2000) in their study in Abeokuta, Nigeria found that soil organic matter content range in uncontaminated sites was 3.25- 3.40% while in dumpsites it was 5.79- 7.59%.

Table 3.17: Organic matter levels in soils

Sampling point	% Organic matter levels in soils for rainy season	% Organic matter levels in soils for dry season
Chirimba stream at Cori	3.101 ± 0.102	1.971 ± 0.313
Chirimba stream at Machinjiri road	4.759 ± 0.327	4.789 ± 0.303
Mudi stream at SRN	4.455 ± 1.764	5.674 ± 0.379
Mudi stream at MDI	0.588 ± 0.428	0.880 ± 0.658
Michiru stream	2.727 ± 0.680	2.732 ± 0.668
Naperi stream at Rainbow paints	4.082 ± 1.184	4.021 ± 0.392
Naperi stream at Moi road	3.921 ± 0.302	0.559 ± 0.304
Blantyre WWTP	9.266 ± 0.404	7.755 ± 0.778
Nasolo stream at BNC	2.460 ± 0.858	3.310 ± 0.042
Nasolo stream at SRN	2.923 ± 0.806	2.691 ± 0.445
Mangunda Stream	1.729 ± 0.228	9.357 ± 0.525
Soche WWTP	6.702 ± 0.807	5.834 ± 0.179
Limbe WWTP	1.604 ± 0.050	0.582 ± 0.203
Limbe stream at Mpingwe	0.873 ± 0.832	1.866 ± 0.134
Limbe stream at Highway	2.37 ± 0.731	2.019 ± 0.286

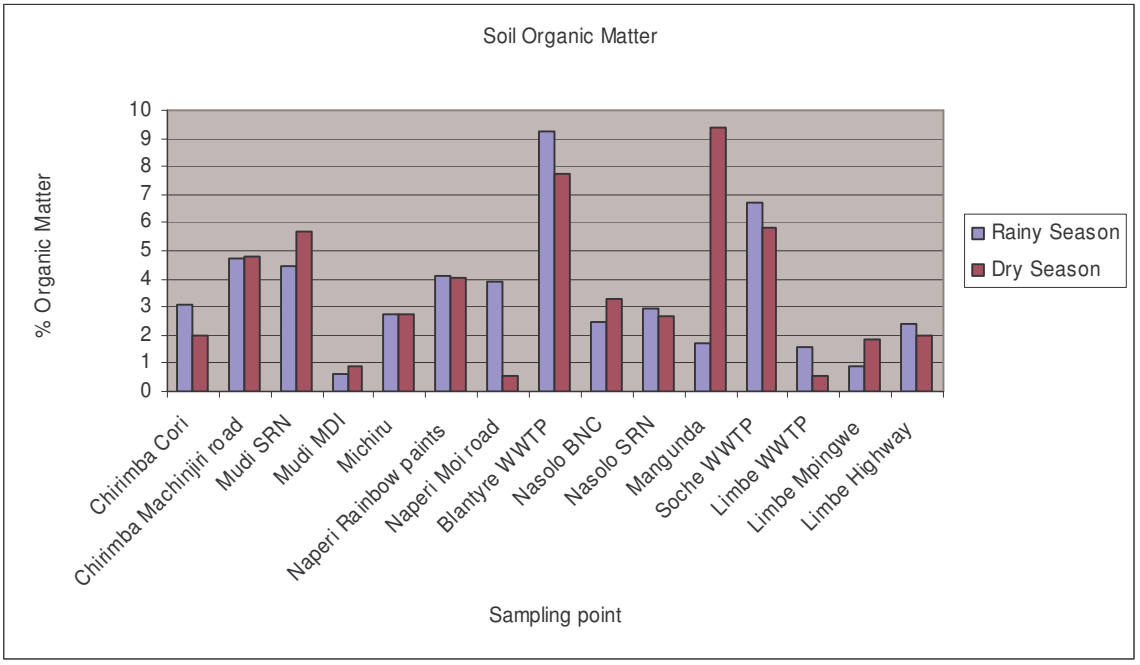


Figure 3.1: Soil organic matter percentage for rainy season and dry season

3.4 pH

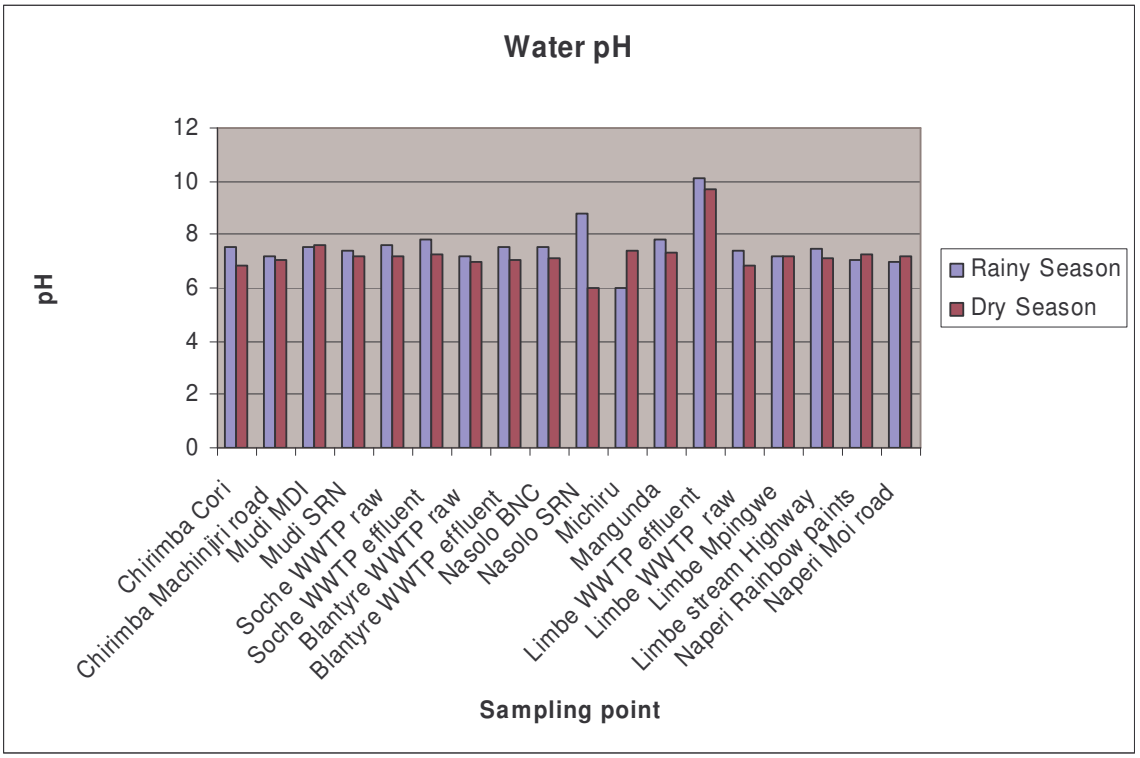
3.4.1 Water pH

In the rainy season, the pH range for water samples was 5.99 – 10.13 while in the dry season it was 5.98 – 9.68 (Figure 3.2). In comparing the rainy season and dry season

values, the differences were insignificant ($p > 0.05$, Appendix 3, Table 17). These results were not very different from the studies done by Sajidu et al. (2006) who found the range of pH to be 6.63 ± 0.14 – 9.38 ± 0.20 in streams and wastewater treatment plants of Blantyre. In both the rainy and dry season 6% of the values did not fall within MBS (5.0 – 9.5) pH range while 11% of the values did not fall within WHO (6.5 – 8.5) standard pH range. In the rainy season, 6% of the samples had low pH as compared to 22% in dry season, which increases the availability of metals in water because it dissolves metal-carbonate complexes, releasing free metal ions into the water column (Connell et al., 1984).

Table 3.18: Water pH

Sampling point	Water pH for rainy season	Water pH for dry season
Chirimba stream at Cori	7.53	6.81
Chirimba stream at Machinjiri road	7.22	7.05
Mudi stream at MDI	7.54	7.58
Mudi stream at SRN	7.39	7.19
Soche WWTP raw sewage	7.62	7.21
Soche WWTP effluent	7.79	7.25
Blantyre WWTP raw sewage	7.2	6.98
Blantyre WWTP effluent	7.55	7.04
Nasolo stream at BNC	7.53	7.13
Nasolo stream at SRN	8.8	5.98
Michiru stream	5.99	7.37
Mangunda stream	7.79	7.32
Limbe WWTP effluent	10.13	9.68
Limbe WWTP raw sewage	7.4	6.84
Limbe stream at Mpingwe	7.19	7.18
Limbe stream at Highway	7.46	7.12
Naperi stream at Rainbow paints	7.06	7.28
Naperi stream at Moi road	7.01	7.19



MBS pH drinking water standard (5.0 – 9.5)
WHO pH drinking water standard (6.5 – 8.5)

Figure 3.2: Water pH for rainy season and dry season

3.4.2 Soil pH

In the rainy season, the range of soil pH was 6.47 – 8.37 while in the dry season it was 6.27 – 7.75 (Figure 3.3). Rainy season soil pH levels were significantly higher than those of dry season ($p < 0.05$, Appendix 3, Table 17). This could mostly be attributed to surface run-off. The levels of soil pH (47% in the rainy season and 20% in the dry season) were conducive to the availability of heavy metals in soils since cations are strongly sorbed at high pH (Section 1.5). These values were not far from pH values found elsewhere. Bamgbose et.al (2000) in their study in Abeokuta, Nigeria found that soil pH range in uncontaminated sites was 5.40- 6.74 while in dumpsites it was 7.44- 10.10. Average soil pH values for soils in Illinois, USA vary from mildly alkaline (7.0-7.5) to strongly acid (5.2-5.5) in extreme southern Illinois (ISWS, 2003).

Table 3.19: Soil pH

Sampling point	Soil pH for rainy season	Soil pH for dry season
Chirimba stream at Cori	7.93	7.3
Chirimba stream at Machinjiri road	6.94	6.27
Mudi stream at SRN	6.73	7.22
Mudi stream at MDI	6.95	6.62
Michiru stream	6.47	6.63
Naperi stream at Rainbow paints	7.03	6.52
Naperi stream at Moi road	7.26	6.67
Blantyre WWTP	6.47	6.33
Nasolo stream at BNC	7.21	6.89
Nasolo stream at SRN	7.22	6.94
Mangunda (Mzedi) Stream	6.47	6.37
Soche WWTP	6.52	6.31
Limbe WWTP	7.56	6.68
Limbe stream at Mpingwe	6.93	6.5
Limbe stream at Highway	7.82	7.06

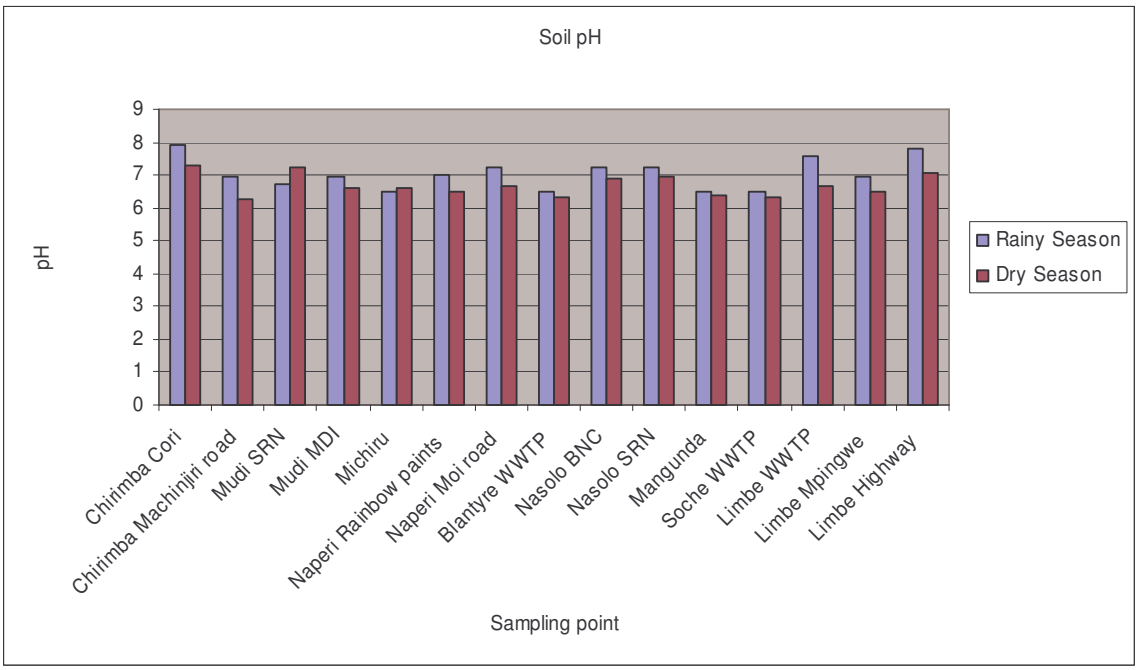


Figure 3.3: Soil pH for rainy season and dry season

CHAPTER 4
4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The study generally found that concentration of heavy metals in the filamentous green algae (*Spirogyra aequinoctialis*) was on the higher side as compared to that in water. The results showed that *S. aequinoctialis* accumulates heavy metals and can therefore be used as a biological indicator which was in agreement to studies done in other countries on other algae species. Water samples were also compared against WHO and MBS standards whereby most of the values under this study were above limits. It was also found that the general trend was that of high heavy metal values for water samples in the dry season than in the rainy season. The low heavy metal levels in the rainy season were attributed to dilution.

The concentration of heavy metals in soils was found to be generally on the higher side unlike that of the earthworms (*Aporrectodea icteria).* The results showed that *A. icteria* cannot be used as a biological indicator since it only accumulated cadmium. Soil samples were also compared to acceptable heavy metal limits for other countries whereby most of the values under this study were on the lower side.

There were no significant differences ($p > 0.05$) in organic matter content in soils for the rainy (0.588 - 9.266%) and the dry season (0.559- 9.357%). About half of the soil samples in both seasons had organic matter levels (3 – 5%) conducive to the binding of heavy metals. There were also no significant differences ($p > 0.05$) in water pH range for rainy season (5.99- 10.13) and dry season (5.98- 9.68). Only few of the sampling points (6% in the rainy season and 22% in the dry season) had low pH which dissolves metal – carbonate complexes releasing free metal ions into water. However, there were significant differences ($p < 0.05$) in soil pH between the rainy (6.47- 8.37) and the dry season (6.27- 7.75). Only 20% of the soil samples in the dry season had pH levels conducive to the availability of metals (above 7) as compared to 40% in the rainy season.

4.2 Recommendations

Blantyre City Assembly should start monitoring heavy metals especially in streams by using *S. aequinoctialis*. *A. icteria*, as this study has shown cannot be used to monitor levels of heavy metals in soils.

Blantyre City Assembly should frequently maintain broken sewer lines as these are contributing to stream metal pollution (especially those carrying industrial wastewater). They have to also look at the best way possible on how they can handle heavy metals in the wastewater treatment plants since these were originally designed to handle organic wastes but with time heavy metals have been finding there way into them.

Most industries in Blantyre have on-site wastewater treatment plants, which reduce pollution load before discharging the effluent into municipal sewer lines. The sewer lines take the industrial wastewater mainly to Blantyre wastewater treatment plant. However it was noted that most of the streams had high levels of heavy metals after passing through an industrial area. This indicates that untreated industrial wastes still find there way into streams. This calls for action by Blantyre City Assembly to caution those industries that are polluting the streams through direct discharges of wastewater into streams or those that have inefficient on-site wastewater treatment plants.

Mzedi dumpsite should be relocated to Chigumula an area identified by the Geological Survey Department (S. Phiri, *Personal Communication*, 2006). This is because there is improper dumping of wastes as such it contributes to pollution of Mangunda stream as shown by this study and Zembere et al. (1999).

Areas requiring further research;

Further research should be done on other species of algae and earthworms so that the best accumulator of heavy metals can be used for monitoring activities.

There is need for research in other pollution monitoring activities using biological assessments (Section 1.2) so that the best approach for Malawi is identified.

Blantyre City Assembly, Malawi Bureau of Standards, Environmental Affairs Department and University of Malawi should facilitate studies in the development of soil standards.

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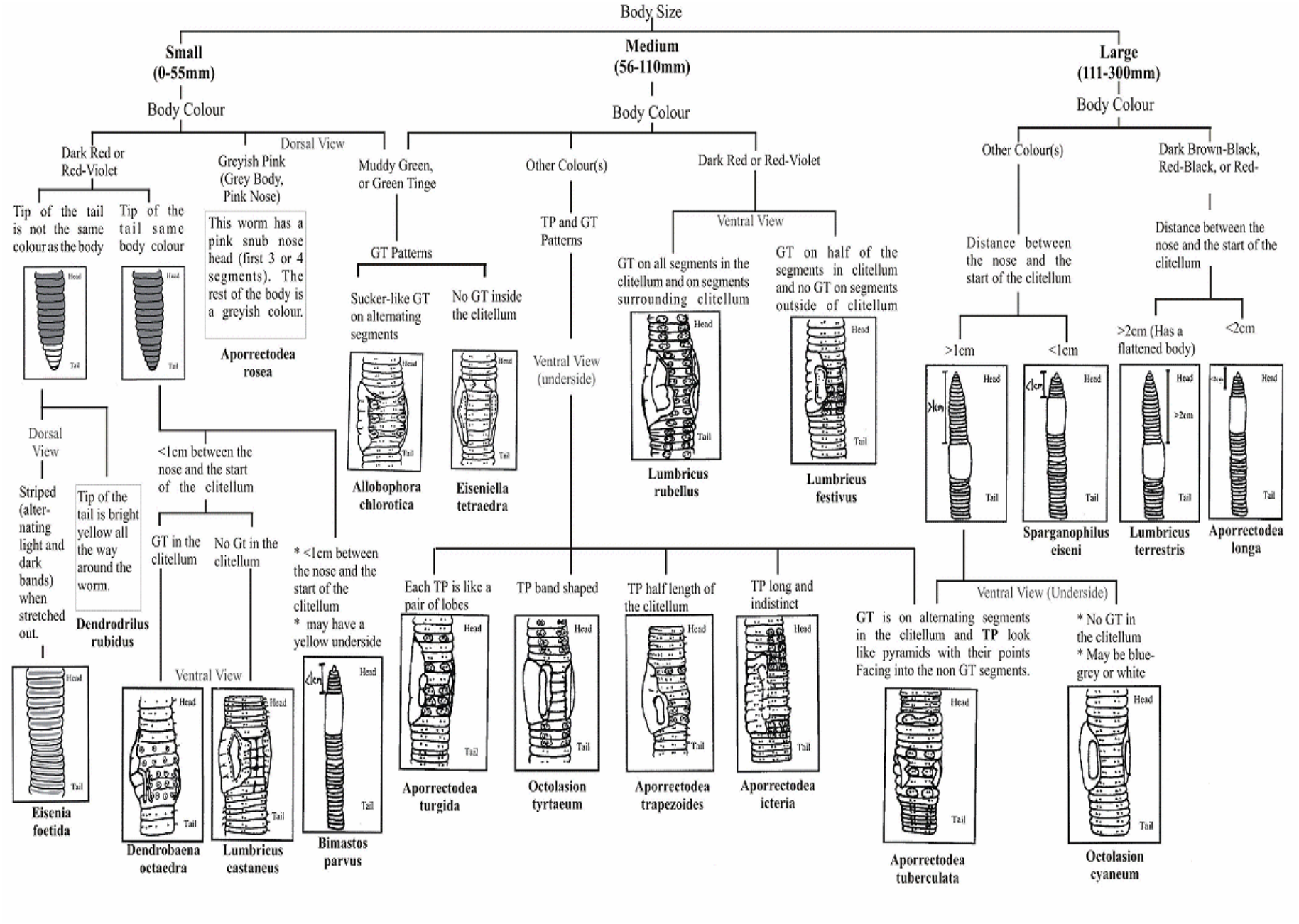
6.0 APPENDICES

Appendix 1: GPS points that were used to draw map for sampling points

Location	Accuracy	Altitude	Easting	Northing
Chirimba stream at Cori	4	930	717311	8259321
Chirimba stream at Machinjiri road	6	923	716993	8259535
Mudi stream at S.R Nicholas	5	1049	716257	8253670
Mudi stream at MDI	6	1128	718113	8253013
Michiru stream	7	-	711239	8256511
Naperi stream at Rainbow paints	5	1137	719643	8251836
Naperi stream at Moi road	5	1098	717874	8251564
Bt WWTP	5	945	713070	8251366
Nasolo stream at BNC	4	1060	716900	8254123
Nasolo stream at S.R Nicholas	5	1049	716257	8253670
Mangunda	5	-	724693	825440
Soche WWTP	4	1022	715002	8250210
Limbe WWTP	4	1119	720015	8247553
Limbe stream at Mpingwe	5	1200	721652	8251661
Limbe stream at highway	5	1160	720695	8251342

Appendix 2; Key for identifying earthworms (Worm watch, 2000)



Appendix 3; Independent sample T- test tables

Table 1; Comparison of manganese in water and algae (*S. aequinoctialis)*

INDEPENDENT SAMPLES TEST										
Comparison of;		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% Confidence Interval of the Difference	
									Lower	Upper
Water Mn (Dry season & rainy season)	Equal variances assumed	10.397	.003	-5.695	34	.000	-.305	5.35E-02	-.414	-.196
	Equal variances not assumed			-5.695	29.422	.000	-.305	5.35E-02	-.414	-.195
Algae Mn (Dry season & rainy season)	Equal variances assumed	8.395	.007	-2.524	34	.016	-2.822	1.118	-5.094	-.55
	Equal variances not assumed			-2.524	20.800	.020	-2.822	1.118	-5.148	-.496
Water & Algae Mn (Rainy season)	Equal variances assumed	45.115	.000	6.939	34	.000	2.482	.358	1.755	3.209
	Equal variances not assumed			6.939	17.232	.000	2.482	.358	1.728	3.236
Water & Algae Mn (Dry season)	Equal variances assumed	21.206	.000	4.714	34	.000	4.999	1.061	2.844	7.155
	Equal variances not assumed			4.714	17.060	.000	4.999	1.061	2.762	7.236

Table 2; Comparison of cadmium in water and algae (*S. aequinoctialis)*

INDEPENDENT SAMPLES TEST										
Comparison of;		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% Confidence Interval of the Difference	
									Lower	Upper
Water Cd (Dry season & rainy season)	Equal variances assumed	20.686	.000	1.653	34	.108	1.202E-02	7.27E-03	-2.757E-03	2.679E-02
	Equal variances not assumed			1.730	22.338	.097	1.201E-02	6.944E-03	-2.373E-03	2.641E-02
Algae Cd (Dry season & rainy season)	Equal variances assumed	38.518	.000	-4.168	34	.000	-.299	7.184E-02	-.445	-.153
	Equal variances not assumed			-4.412	18.072	.000	-.299	6.787E-02	-.442	-.157
Water & Algae Cd (Rainy season)	Equal variances assumed	.066	.799	-13.836	34	.000	-7.126E-02	5.150E-03	-8.173E-02	-6.079E-02
	Equal variances not assumed			-14.103	32.355	.000	-7.126E-02	5.053E-03	-8.155E-02	-6.097E-02
Water & Algae Cd (Dry season)	Equal variances assumed	36.089	.000	3.993	34	.000	.272	6.805E-02	.133	.410
	Equal variances not assumed			3.774	16.282	.002	.272	7.199E-02	.119	.424

Table 3; Comparison of copper in water and algae (*S. aequinoctialis)*

INDEPENDENT SAMPLES TEST										
Comparison of;		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% Confidence Interval of the Difference	
									Lower	Upper
Water Cu (Dry season & rainy season)	Equal variances assumed	64.472	.000	-5.010	34	.000	-2.96E-02	5.912E-03	-4.162E-02	-1.8E-02
	Equal variances not assumed			-5.010	17.000	.000	-2.961E-02	5.912E-03	-4.208E-02	-1.7E-02
Algae Cu (Dry season & rainy season)	Equal variances assumed	11.374	.002	-2.508	34	.017	-.414	.165	-.750	-7.9E-02
	Equal variances not assumed			-2.508	20.260	.021	-.414	.165	-.758	-7.0E-02
Water & Algae Cu (Rainy season)	Equal variances assumed	19.228	.000	4.275	34	.000	.210	4.906E-02	.110	.309
	Equal variances not assumed			4.275	17.000	.001	.210	4.906E-02	.1062	.313
Water & Algae Cu (Dry season)	Equal variances assumed	23.173	.000	3.766	34	.001	.594	.158	.274	.915
	Equal variances not assumed			3.766	17.048	.002	.594	.158	.261	.927

Table 4; Comparison of iron in water and algae (*S. aequinoctialis)*

INDEPENDENT SAMPLES TEST										
Comparison of;		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% Confidence Interval of the Difference	
									Lower	Upper
Water Fe (Dry season & rainy season)	Equal variances assumed	1.103	.301	-1.811	34	.079	-.437	.241	-.928	5.34E-02
	Equal variances not assumed			-1.811	33.977	.079	-.437	.241	-.928	5.34E-02
Algae Fe (Dry season & rainy season)	Equal variances assumed	3.730	.062	1.394	34	.172	9.783	7.016	-4.476	24.041
	Equal variances not assumed			1.394	30.266	.173	9.783	7.016	-4.541	24.106
Water & Algae Fe (Rainy season)	Equal variances assumed	49.919	.000	14.281	34	.000	57.119	3.400	48.991	65.248
	Equal variances not assumed			14.281	17.064	.000	57.119	3.400	48.683	65.556
Water & Algae Fe (Dry season)	Equal variances assumed	54.016	.000	8.129	34	.000	46.900	5.769	35.175	58.624
	Equal variances not assumed			8.129	17.029	.000	46.900	5.769	34.729	59.070

Table 5; Comparison of zinc in water and algae (*S. aequinoctialis)*

INDEPENDENT SAMPLES TEST										
Comparison of;		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% Confidence Interval of the Difference	
									Lower	Upper
Water Zn (Dry season & rainy season)	Equal variances assumed	7.424	.010	5.272	34	.000	.639	.121	.392	.885
	Equal variances not assumed			5.272	17.844	.000	.634	.121	.384	.893
Algae Zn (Dry season & rainy season)	Equal variances assumed	3.246	.080	-.679	34	.501	-.320	.471	-1.276	0.63656
	Equal variances not assumed			-.679	26.721	.503	-.320	.471	-1.286	0.646
Water & Algae Zn (Rainy season)	Equal variances assumed	12.491	.001	3.626	34	.001	.940	.259	.413	1.467
	Equal variances not assumed			3.626	25.575	.001	.940	.259	.407	1.474
Water & Algae Zn (Dry season)	Equal variances assumed	24.771	.000	4.621	34	.000	1.899	.411	1.064	2.734
	Equal variances not assumed			4.621	17.072	.000	1.899	.411	1.032	2.765

Table 6; Comparison of lead in water and algae (*S. aequinoctialis)*

INDEPENDENT SAMPLES TEST										
Comparison of;		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% Confidence Interval of the Difference	
									Lower	Upper
Water Pb (Dry season & rainy season)	Equal variances assumed	4.182	.049	-1.259	34	.217	-1.743E-02	1.385E-02	-4.557E-02	1.071E-02
	Equal variances not assumed			-1.259	23.762	.220	-1.743E-02	1.385E-02	-4.603E-02	1.116E-02
Algae Pb (Dry season & rainy season)	Equal variances assumed	.301	.587	-1.091	34	.283	-1.000E-01	9.166E-02	-.286	8.63E-02
	Equal variances not assumed			-1.091	33.903	.283	-1.000E-01	9.166E-02	-.286	8.63E-02
Water & Algae Pb (Rainy season)	Equal variances assumed	16.349	.000	2.719	34	.010	.172	6.332E-02	4.347E-02	.30084
	Equal variances not assumed			2.719	17.282	.014	.1722	6.332E-02	3.873E-02	.306
Water & Algae Pb (Dry season)	Equal variances assumed	22.083	.000	3.762	34	.001	.255	6.771E-02	.117	.392
	Equal variances not assumed			3.762	18.218	.001	.255	6.771E-02	.113	.397

Table 7; Comparison of chromium in water and algae (*S. aequinoctialis)*

INDEPENDENT SAMPLES TEST										
Comparison of;		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% Confidence Interval of the Difference	
									Lower	Upper
Water Cr (Dry season & rainy season)	Equal variances assumed	14.117	.001	-1.800	34	.081	-6.122E-02	3.401E-02	-.130	7.901E-03
	Equal variances not assumed			-1.800	18.380	.088	-6.122E-02	3.401E-02	-.133	1.013E-02
Algae Cr (Dry season & rainy season)	Equal variances assumed	.983	.328	-.763	34	.451	-3.983E-02	5.223E-02	-.146	6.630E-02
	Equal variances not assumed			-.763	29.499	.452	-3.983E-02	5.223E-02	-.147	6.690E-02
Water & Algae Cr (Rainy season)	Equal variances assumed	11.732	.002	1.964	34	.058	5.661E-02	2.883E-02	-1.974E-03	.115
	Equal variances not assumed			1.964	17.000	.066	5.661E-02	2.883E-02	-4.210E-03	.117
Water & Algae Cr (Dry season)	Equal variances assumed	.135	.715	.520	34	.607	2.850E-02	5.485E-02	-8.296E-02	.140
	Equal variances not assumed			.520	31.834	.607	2.850E-02	5.485E-02	-8.324E-02	.1402

Table 8; Comparison of nickel in water and algae (*S. aequinoctialis)*

INDEPENDENT SAMPLES TEST										
Comparison of;		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% Confidence Interval of the Difference	
									Lower	Upper
Water Ni (Dry season & rainy season)	Equal variances assumed	20.719	.000	1.274	34	.211	4.722E-02	3.705E-02	-2.808E-02	.123
	Equal variances not assumed			1.274	19.912	.217	4.722E-02	3.705E-02	-3.009E-02	.125
Algae Ni (Dry season & rainy season)	Equal variances assumed	1.249	.272	-1.110	34	.275	-4.522E-02	4.075E-02	-.128	3.760E-02
	Equal variances not assumed			-1.110	32.388	.275	-4.522E-02	4.075E-02	-.128	3.775E-02
Water & Algae Ni (Rainy season)	Equal variances assumed	4.387	.044	-1.170	34	.250	-2.509	2.145	-6.867	1.850
	Equal variances not assumed			-1.170	17.005	.258	-2.509	2.145	-7.034	2.016
Water & Algae Ni (Dry season)	Equal variances assumed	1.135	.294	-5.685	34	.000	-.271	4.774E-02	-.368	-.174
	Equal variances not assumed			-5.685	33.601	.000	-.271	4.774E-02	-.369	-.1744

Table 9; Comparison of manganese in soil and earthworms (*A. icteria*)

INDEPENDENT SAMPLES TEST										
Comparison of;		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% Confidence Interval of the Difference	
									Lower	Upper
Soil Mn (Dry season & rainy season)	Equal variances assumed	12.783	.001	-2.246	28	.033	-4.298	1.914	-8.219	-.377
	Equal variances not assumed			-2.246	16.861	.038	-4.298	1.914	-8.339	-.257
Earthworm Mn (Dry season & rainy season)	Equal variances assumed	.812	.375	.802	28	.429	.596	.743	-.926	2.119
	Equal variances not assumed			.802	25.499	.430	.596	.743	-.933	2.126
Soil & earthworm Mn (Rainy season)	Equal variances assumed	.644	.429	-8.657	28	.000	-8.179	.945	-10.114	-6.244
	Equal variances not assumed			-8.657	27.050	.000	-8.179	.945	-10.117	-6.241
Soil & earthworm Mn (Dry season)	Equal variances assumed	17.571	.000	-7.334	28	.000	-13.740	1.874	-17.578	-9.902
	Equal variances not assumed			-7.334	15.595	.000	-13.740	1.874	-17.720	-9.760

Table 10; Comparison of cadmium in soil and earthworms (*A. icteria*)

INDEPENDENT SAMPLES TEST										
Comparison of;		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% Confidence Interval of the Difference	
									Lower	Upper
Soil Cd (Dry season & rainy season)	Equal variances assumed	30.917	.000	-2.989	28	.006	-5.058E-02	1.692E-02	-8.525E-02	-1.591E-02
	Equal variances not assumed			-2.989	14.761	.009	-5.058E-02	1.692E-02	-8.670E-02	-1.446E-02
Earthworm Cd (Dry season & rainy season)	Equal variances assumed	26.226	.000	-3.746	28	.001	-.1333	3.559E-02	-.206	-6.043E-02
	Equal variances not assumed			-3.502	13.315	.004	-.133	3.807E-02	-.215	-5.128E-02
Soil & Earthworm Cd (Rainy season)	Equal variances assumed	7.240	.012	18.395	28	.000	.119	6.487E-03	.106	.133
	Equal variances not assumed			19.709	15.000	.000	.119	6.055E-03	.106	.132
Soil & Earthworm Cd (Dry season)	Equal variances assumed	5.986	.021	4.523	28	.000	.192	4.234E-02	.105	.278
	Equal variances not assumed			4.742	20.973	.000	.192	4.039E-02	.108	.276

Table 11; Comparison of copper in soil and earthworms (*A. icteria*)

INDEPENDENT SAMPLES TEST										
Comparison of;		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% Confidence Interval of the Difference	
									Lower	Upper
Soil Cu (Dry season & rainy season)	Equal variances assumed	4.790	.037	-1.301	28	.204	-1.132	.870	-2.914	.650
	Equal variances not assumed			-1.301	20.535	.208	-1.132	.870	-2.943	.680
Earthworm Cu (Dry season & rainy season)	Equal variances assumed	1.929	.176	.360	28	.722	3.927E-02	.109	-.184	.263
	Equal variances not assumed			.360	16.195	.723	3.927E-02	.109	-.192	.270
Soil & Earthworm Cu (Rainy season)	Equal variances assumed	8.387	.007	-3.576	28	.001	-1.436	.402	-2.259	-.613
	Equal variances not assumed			-3.576	16.044	.003	-1.436	.402	-2.287	-.585
Soil & Earthworm Cu (Dry season)	Equal variances assumed	19.604	.000	-3.345	28	.002	-2.607	.779	-4.203	-1.011
	Equal variances not assumed			-3.345	14.040	.005	-2.607	.779	-4.278	-.936

Table 12; Comparison of iron in soil and earthworms (*A. icteria*)

INDEPENDENT SAMPLES TEST										
Comparison of;		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% Confidence Interval of the Difference	
									Lower	Upper
Soil Fe (Dry season & rainy season)	Equal variances assumed	2.599	.118	2.490	28	.019	16.175	6.497	2.868	29.483
	Equal variances not assumed			2.490	26.969	.019	16.175	6.497	2.845	29.506
Earthworm Fe (Dry season & rainy season)	Equal variances assumed	1.915	.177	2.295	28	.029	9.715	4.233	1.044	18.385
	Equal variances not assumed			2.295	24.444	.031	9.715	4.233	.987	18.442
Soil & Earthworm Fe (Rainy season)	Equal variances assumed	5.988	.021	-8.497	28	.000	-20.458	2.408	-25.390	-15.526
	Equal variances not assumed			-8.497	15.290	.000	-20.458	2.408	-25.581	-15.334
Soil & Earthworm Fe (Dry season)	Equal variances assumed	25.569	.000	8.919	28	.000	44.801	5.023	34.512	55.090
	Equal variances not assumed			8.919	14.001	.000	44.801	5.023	34.028	55.574

Table 13; Comparison of zinc in soil and earthworms (*A. icteria*)

INDEPENDENT SAMPLES TEST										
Comparison of;		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% Confidence Interval of the Difference	
									Lower	Upper
Soil Zn (Dry season & rainy season)	Equal variances assumed	2.840	.103	1.864	28	.073	3.027	1.624	-.300	6.354
	Equal variances not assumed			1.864	24.197	.075	3.027	1.624	-.324	6.377
Earthworm Zn (Dry season & rainy season)	Equal variances assumed	5.281	.029	2.270	28	.031	1.130	.497	.110	2.148
	Equal variances not assumed			2.270	24.785	.032	1.129	.497	.104	2.154
Soil & Earthworm Zn (Rainy season)	Equal variances assumed	17.105	.000	-3.257	28	.003	-4.263	1.309	-6.945	-1.582
	Equal variances not assumed			-3.257	15.353	.005	-4.263	1.309	-7.048	-1.479
Soil & Earthworm Zn (Dry season)	Equal variances assumed	2.849	.103	-1.798	28	.083	-1.766	.982	-3.777	.246
	Equal variances not assumed			-1.798	19.666	.087	-1.766	.982	-3.817	.285

Table 14; Comparison of lead in soil and earthworms (*A. icteria*)

INDEPENDENT SAMPLES TEST										
Comparison of;		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% Confidence Interval of the Difference	
									Lower	Upper
Soil Pb (Dry season & rainy season)	Equal variances assumed	3.129	.088	1.225	28	.231	.419	.345	-.281	1.119
	Equal variances not assumed			1.225	23.955	.232	.419	.342	-.287	1.124
Earthworm Pb (Dry season & rainy season)	Equal variances assumed	.232	.634	-.936	28	.358	-7.033E-02	7.518E-02	-.224	8.37E-02
	Equal variances not assumed			-.936	25.516	.358	-7.033E-02	7.518E-02	-.225	8.43E-02
Soil & Earthworm Pb (Rainy season)	Equal variances assumed	12.769	.001	-8.019	28	.000	-1.565	.195	-1.964	-1.165
	Equal variances not assumed			-8.019	16.986	.000	-1.565	.195	-1.977	-1.153
Soil & Earthworm Pb (Dry season)	Equal variances assumed	23.430	.000	-3.706	28	.001	-1.076	.290	-1.671	-.481
	Equal variances not assumed			-3.706	14.661	.002	-1.076	.290	-1.696	-.456

Table 15; Comparison of chromium in soil and earthworms (*A. icteria*)

INDEPENDENT SAMPLES TEST										
Comparison of;		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% Confidence Interval of the Difference	
									Lower	Upper
Soil Cr (Dry season & rainy season)	Equal variances assumed	.694	.412	.037	28	.971	2.773E-02	.755	-1.518	1.574
	Equal variances not assumed			.037	26.093	.971	2.773E-02	.755	-1.523	1.579
Earthworm Cr (Dry season & rainy season)	Equal variances assumed	31.064	.000	-2.330	28	.027	-6.667E-03	2.861E-03	-1.253E-02	-8.1E-04
	Equal variances not assumed			-2.330	14.000	.035	-6.667E-03	2.861E-03	-1.280E-02	-5.3E-04
Soil & Earthworm Cr (Rainy season)	Equal variances assumed	16.414	.000	-4.246	28	.000	-1.936	.456	-2.869	-1.002
	Equal variances not assumed			-4.246	14.000	.001	-1.936	.456	-2.913	-.958
Soil & Earthworm Cr (Dry season)	Equal variances assumed	17.212	.000	-3.160	28	.004	-1.901	.602	-3.133	-.669
	Equal variances not assumed			-3.160	14.001	.007	-1.901	.602	-3.191	-.611

Table 16; Comparison of nickel in soil and earthworms (*A. icteria*)

INDEPENDENT SAMPLES TEST										
Comparison of;		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% Confidence Interval of the Difference	
									Lower	Upper
Soil Ni (Dry season & rainy season)	Equal variances assumed	2.976	.096	-.781	28	.442	-.338	.433	-1.225	.549
	Equal variances not assumed			-.781	23.741	.443	-.338	.433	-1.232	.556
Earthworm Ni (Dry season & rainy season)	Equal variances assumed	4.734	.038	-.127	28	.900	-1.053E-02	8.265E-02	-.180	.1588
	Equal variances not assumed			-.127	22.615	.900	-1.053E-02	8.265E-02	-.182	.161
Soil & Earthworm Ni (Rainy season)	Equal variances assumed	15.475	.001	-3.047	28	.005	-.720	.236	-1.203	-.236
	Equal variances not assumed			-3.047	14.905	.008	-.719	.236	-1.223	-.216
Soil & Earthworm Ni (Dry season)	Equal variances assumed	2.849	.103	-1.798	28	.083	-1.766	.982	-3.777	.246
	Equal variances not assumed			-1.798	19.666	.087	-1.766	.982	-3.817	.285

Table 17; Comparison of soil organic matter, water pH and soil pH

INDEPENDENT SAMPLES TEST										
Comparison of;		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% Confidence Interval of the Difference	
									Lower	Upper
Soil organic matter (Dry season & rainy season)	Equal variances assumed	.251	.619	.389	34	.700	.310	.797	-1.310	1.930
	Equal variances not assumed			.389	33.772	.700	.310	.797	-1.310	1.930
Water pH (Dry season & rainy season)	Equal variances assumed	.408	.527	1.306	34	.200	.333	.255	-.185	.852
	Equal variances not assumed			1.306	32.975	.200	.333	.255	-.186	.852
Soil pH (Dry season & rainy season)	Equal variances assumed	2.047	.162	2.237	34	.032	.404	.181	3.689E-02	.771
	Equal variances not assumed			2.237	30.620	.033	.404	.181	3.539E-02	.772